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J. H. Lambert

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Office of Sponsored Programs
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Charlottesville, Virginia 22904-4195

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14. ABSTRACT

This research develops a methodology and software assessment tool to implement selected methods and principles of multicriteria analysis and risk analysis for selecting among energy security investments and strategies. The approach enables decision makes to address a broad and varying range of emergent conditions in the energy environment including mission criticality, regulatory and market forces, disruption of service, grid failure, infrastructure deterioration, and others. With a set of performance criteria, the multicriteria methodology complements and improves on a single economics-based metric for energy investment and security. The methodology provides the relevant risk and opportunity tradeoffs to compare various energy security investments and strategies. The process involves identifying (i) multiple criteria and requirements describing energy security, (ii) several energy security design alternatives for comparison, and (iii) emergent conditions that present a risk or opportunity to investment alternatives. The approach is demonstrated in a case study that describes the implementation of the methodology at the Area 300 Compound at Ft. Belvoir.

15. SUBJECT TERMS
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Glossary

The following terms are relevant for the methodology and software workbook tool:

Baseline scenario — The business-as-usual scenario or the idea that future conditions are similar to the current conditions.

Conceptual design — A description of an investment or strategy that is feasible to build given constraint and requirements. Also described as a decision alternative.

Criterion/requirement — A statement related to a goal that the alternatives should achieve.

Emergent condition — A future event or trend, likely or unlikely, which could affect the desirability of different feasible alternatives. Key categories for emergent conditions include changes in regulation/legislation (environmental, technology, etc.), nature or public/private relationships (utilities), prices/costs/availabilities of resources, technology changes, trends in episodic events (hurricanes, earthquakes, accidents, floods, droughts, terrorism, cyberattacks, etc.), changes in installation/mission/customer requirements, and others.

Microgrid — A localized grouping of electricity generation, energy storage, and loads that normally operates connected to a traditional centralized grid. This single point of common coupling with the centralized grid can be disconnected and function autonomously. Microgrid generation resources can include fuel cells, wind, solar, or other energy sources. Byproduct heat from generation sources such as microturbines could be used for local process heating or space heating, allowing flexible trade off between the needs for heat and electric power.

Multiple criteria decision analysis — A method for structuring and solving decision and planning problems involving multiple criteria where decision maker's preferences are used to differentiate between solutions.

Near-robust alternative — For some conceptual design alternatives, one is able to identify a scenario for which the alternative is robust in all other scenarios, but drops in ranking for this particular scenario. This scenario is defined as a *threot* to the *neor-robust* alternative.

Opportunity — A scenario for an alternative that is not ranked highly in other scenarios is ranked highly in the scenario.

Risk analysis - A technique to identify and assess factors that may jeopardize the success of a project or achieving a goal. Risk analysis is used to identify potential Issues ahead of time before they pose negative impacts.

Robust alternative — An alternative that is ranked highly in all scenarios.

Scenario— The combination of one or more emergent conditions.

Scenario analysis - A process designed to improve decision making by analyzing several possible future events and their implications. Scenario analysis presents several alternative future developments instead of one exact picture of the future.

Software workbook tool – The Microsoft Excel workbook that has been created to facilitate the process of evaluating conceptual designs against multiple criteria with consideration of multiple scenarios. The software workbook tool requires user input of conceptual designs, criteria, and scenarios, and produces a prioritized ranking of conceptual designs for each scenario.

Threat —A scenario that drops a near-robust alternative in the prioritization order.

Worksheet tab – A single tab within the software workbook tool.

Acknowledgements

Executive Summary

This report describes a methodology and software assessment tool to implement selected methods and principles of multicriteria analysis and risk analysis for selecting among energy security investments and strategies. The approach enables decision makers to address a broad and varying range of emergent conditions in the energy environment including mission criticality, regulatory and market forces, disruption of service, grid failure, infrastructure deterioration, and others. With a set of performance criteria, the multicriteria-based methodology complements and improves on a single economics-based metric for energy investment and security. The methodology provides the relevant risk and opportunity tradeoffs to compare various energy security investments and strategies. The process involves identifying (i.) multiple criteria and requirements describing energy security, (ii) several energy security conceptual design alternatives for comparison, and (iii) emergent or future conditions that present a risk or opportunity to investment alternatives. The methodology is implemented in a software workbook tool, entitled *Energy Security: A Project Selection Tool.* The purpose of the software tool is to implement the methodology and elicit and structure the evaluation of energy security conceptual design alternatives.

The accomplishments of this effort are:

- Supported a case study site to identify effective technology alternatives and influential emergent/future conditions
- Recommended particular technologies, including gas turbines for the present, landfill gas, and liquid natural gas into the future
- Convened a stakeholder workshop to address cyber threat, security of gas reservoirs, regulations, etc.
- Tested the software tool with a dozen of the working group of military, industry, energy managers, tenants, vendors, others
- Published or submitted more than five archival papers, more than a dozen conference presentations or papers, and two book chapters

The report describes stakeholder collaboration and iteration with support of the methodology, lessons learned, future recommendations, resources for future implementation, policy documents, and training experiences. The approach is demonstrated throughout this report in a case study that describes the implementation of the methodology at the Area 300 Compound at Ft. Belvoir, an installation in Fairfax Count, Virginia.

1. Introduction

This report describes a methodology within web-based software to implement methods and principles of multicriteria analysis and risk analysis for selecting among energy security investments and strategies for an installation. The approach enables decision makers to address a broad and varying range of emergent conditions in the energy environment including mission criticality, regulatory and market forces, disruption of service, grid failure, infrastructure deterioration, and so forth. With a set of performance criteria, the methodology complements and improves on a single economics -based metric for energy investment and security. The methodology provides the relevant opportunity, cost, and risk tradeoffs to compare current energy security strategies and technologies to potential investments in energy security while quantifying the impact to missions in their implementation. The generalized and disciplined approach supports incremental adjustments in energy security investment portfolios consisting of strategies and technologies and can account for changes in installation land use and for utility integration or interconnectivity. The approach supports the analysis of islanding of energy generation and distribution networks including electricity, natural gas, steam, liquid fuel, water, and others for the diverse missions that the installations execute or support. The approach is demonstrated throughout this report in a case study that describes the implementation of the methodology at the Area 300 Compound at Ft. Belvoir, an installation in Fairfax Count, Virginia.

This report describes the methodology, supporting software workbook tool, and website for the web-based version of the methodology and tool. The methodology and supporting materials aid in performing multicriteria and scenario analysis for identifying robust energy security investment decisions at installations. The methodology has been developed in several publications (Karvetski et al., 2011a, 2011b, 2009; Lambert et al., 2011, 2010; Martinez et al., 2011) and several other presentations and training sessions identified in Section 12. The purpose of the software workbook tool is to implement the methodology and elicit and structure the evaluation of energy security conceptual design alternatives using multiple performance criteria. The software workbook tool can be used in several phases of design. In this report, we present a case study of a more advanced design phase. Additional workbooks housing other case studies and materials can be downloaded from the website at (http://www.virginia.edu/crmes/energysecurity/). Also included on the website is a survey that aids in eliciting inputs for the tool from the multiple stakeholders that could be involved in the decision making. Training videos and links to relevant Army doctrines are also provided at the website.

There have been four previous letter reports, one midpoint report, and one technical report that this final report builds on. The letter reports include (1) a letter report documenting construction of energy security alternatives and performance criteria (May, 2010), (2) a letter report defining installation energy emergent conditions (September, 2010), (3) a letter report documenting the assembly of MCDA software tool (December, 2010), (4) a letter report documenting the training and testing of the methods (March, 2011), and a technical report outlining the web-basing of the workbook tool and other materials (December, 2011).

The remainder of the report is as follows. The next section describes the methodology and its application in the software workbook tool. Section 3 describes derivation and use of performance criteria in the software workbook tool. Section 4 describes the formation of the conceptual design alternatives. Section S describes the formation of scenarios using multiple emergent and future conditions. Section 6 describes the interpretation of the methodology output. Throughout sections 3 through 6, a case study on Ft. Belvoir is presented, which is in the process of evaluating energy strategies and technologies to provide uninterrupted, quality prime

power for buildings in the Area 300 Compound. The remaining sections of the report describe stakeholder collaboration and iteration with the methodology, lessons learned, future recommendations, project deliverables, and conclusions of the efforts.

2. Overview of methodology and software workbook tool

Installation energy managers are tasked to select a preferred conceptual design alternative, which includes strategies or investment in energy sources, strategies and technologies to provide adequate, reliable energy and water in support of essential and critical missions on the installation. Multiple criteria analysis and scenario analysis can be used to complement and improve on a single economics-based metric for energy investment and security.

This methodology allows users to include multiple performance criteria and requirements into the evaluation of conceptual design alternatives. It also leads allows users through an evaluation of how emergent and future conditions influence the prioritization of conceptual designs through their impacts to the relative weights of performance criteria. The output of the software workbook tool provides a measure of robustness of the prioritization of conceptual design alternatives. The methodology presented in this report leads the user through a systematic process for identifying performance criteria, conceptual design alternatives, and scenarios of emergent and future conditions.

The software workbook tool used to implement the methodology is entitled, *Energy Security: A Project Selection Tool*. The tool is comprised of several worksheets intended to lead the user through a systematic, risk-informed evaluation of energy security alternatives. There are several worksheets requiring user input. Other worksheets are for informational purposes only. Within the software workbook tool, instructions are provided on the top of every worksheet requiring input, and can be viewed by mousing over the cell labeled "Instructions". Figure 1 describes the flow of the methodology and software workbook tool. The software workbook starts with the definition high-level objectives and criteria/requirements and then with the definition of conceptual design alternatives. The alternatives are evaluated on each criterion or requirement and a criterion or requirement ranking or weighting is used to get a prioritization of the alternatives. Then scenarios are formed using multiple future conditions. The scenarios are used to perform sensitivity analysis on the ranked requirements to understand the sensitivity of the prioritization.

These tabs are designed for the user to consider high-level DoD goals such as the Energy Security Goals from the Army Energy Security Implementation Strategy (AESIS), then define the mission or operation objectives, and finally to input and select the mission criticality of supporting requirements.

<<Energy Security Goals (ESGs)>>

Mission-Operation

Requirements and Objectives

Conceptual Design Build

Design Assessment

Design Summary

These tabs guide the user to build the feasible conceptual energy security designs to meet the mission and operation objectives. The designs are assessed using the requirements. The mission criticality factors is then used to aggregate across the requirements to understand how the designs are ranked relative to each other.

These tabs prompt the user to consider what future scenarios could impact how the disigns are prioritized. First the user constructs the scenarios from a menu of emergent and future conditions. Then the user determines how the scenarios of emergent and future conditions influence the mission criticality of the requirements.

<<Impact Analysis>>

Impact Analysis (1)

Impact Analysis (2)

<<Results>>

Top Conceptual Designs

Top Conditions

These tabs display the sensitivity of the conceptual design rankings to the various scenario assumptions. This information gives the user an understanding of (i) what designs perform well across the scenarios, and (ii) what scenarios are opportunities and what scenarios are threats.

The advanced users tab is used to adjust the parameter values of the model. The terms of reference tab and governing documents tab provide a summary of relevant energy security doctrines and policies.

Advanced Users

<<Terms of Reference>>

<<Governing Documents>>

Figure 1: The table of contents tab of the software workbook tool Energy Security: A Project Selection Tool

3. Performance criteria

This section describes the purpose and systematic approach for identifying performance criteria as well as how these principles are applied in the software workbook tool, *Energy Security: A Project Selection Tool.*

3.1 Purpose

The purpose of this step of the methodology is to identifying several criteria on which to evaluate various investment alternatives and weight the criteria on their relative importance. The criteria should be derived from high-level governing documents and specific mission and operation requirements for each installation.

3.2 Systematic approach for identifying performance criteria

The performance criteria are used to evaluate the conceptual design alternatives and serve as a means to understand and quantify the effects of the scenarios of emergent conditions on the desirability and prioritization of alternatives. The criteria should be derived from two sources, i) high-level governing documents, and ii) specific mission and operation requirements for each installation. The AESIS (US Army, 2009) expresses five energy security goals (ESGs; Army, 2009). These include: ESG1 reduced energy consumption, ESG 2 increased energy efficiency across platforms and facilities, ESG 3 increased use of renewable/alternative energy, ESG 4 assured access to sufficient energy supplies, and ESG 5 reduced adverse impacts on the environment. Nevertheless, these goals are broad and not mission specific. Other installation-specific goals should be included.

From broad mission objectives expressed from the Army and Department of Defense (DoD) as well as the individual installation, the user can express qualitative and context-specific criteria. For example, a mission objective may be to have assured energy supply for a specific building that supports a critical mission. A supporting qualitative criterion could be *"maximize available energy"*. From the context-specific mission criteria, the user can derive performance criteria with supporting measures to compare alternatives. Continuing with the example, a performance criterion with a measure would be the kWh storage capacity for the specific building. In addition to other general guidelines and practices, the performance criteria should be independent as possible (not overlapping), unambiguous, and exhaustive in terms of the mission objectives (see e.g., Keeney, 1992). Figure 2 displays this relationship of how the measures that compare alternatives are connected the high-level mission objectives. Also, the criteria should consider the entire investment timeframe. Figure 3 displays how criteria can be formed to measure objectives throughout the lifecycle of the energy system.
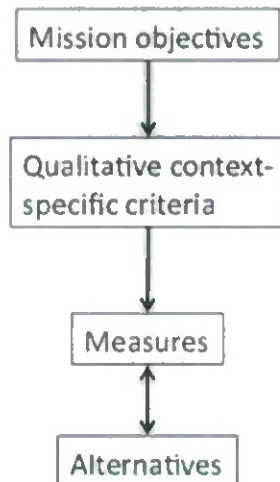
Figure 2. Relationship of mission objectives through measures that compare the alternatives.

Evaluation and Performance Criteria
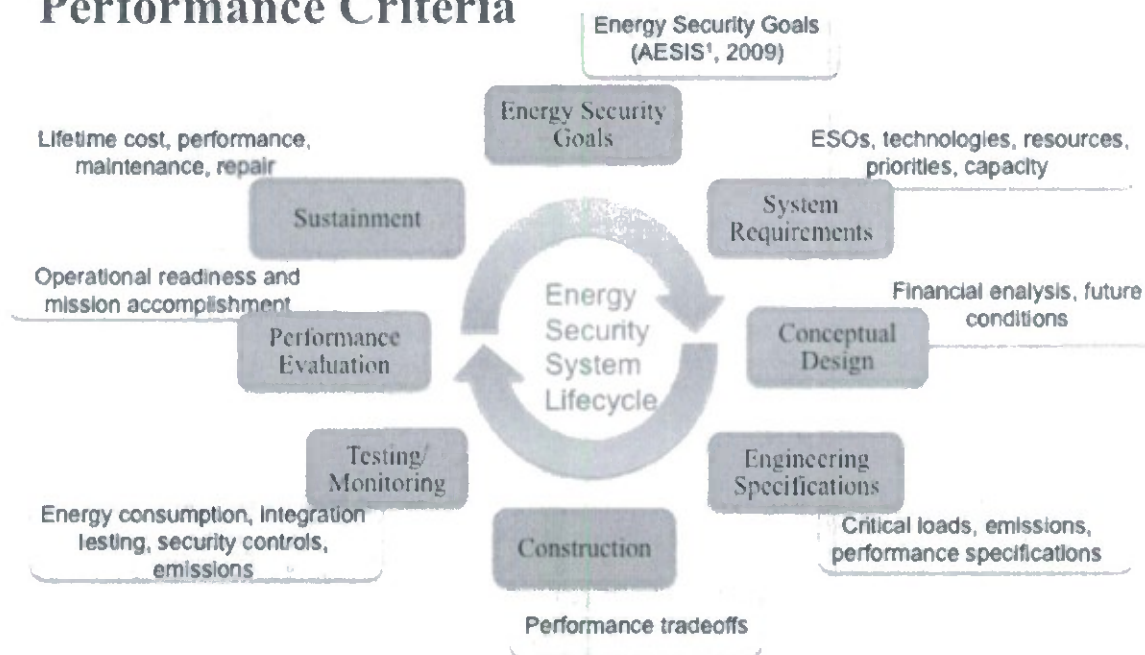
[1]United States Army, 2009. Army Energy Security Implementation Strategy (AESIS).
<http://www.osd.e.army.mil/Public/Pertnerships/doc/AESIS_13JAN09_Approved%204-03-09.pdf>

Figure 3. Objectives, requirements, and criteria should consider all phases of the systems lifecycle

3.3 Application of performance criteria in software workbook

The software workbook tool, *Energy Security: A Project Selection Tool*, assists the user in the development of performance criteria through three worksheets. First, the worksheet tab entitled "<<Energy Security Goals (ESGs)>>" reminds the user of high level Army and DoD goals. Next, in the tab entitled "Mission-Operation", the user is invited to type a narrative in the yellow box that describes why new energy investment alternatives might be needed with respect to the missions and operations of the installation (tab not shown in report). For example, in the Ft. Belvoir case study, the goal is deliver quality prime power to a few key buildings in Area 300 that house scientific experiments.

Next, with the ESGs and mission-operation in mind, the criteria are tailored and augmented for specific missions and operations described by the user at the installation. In the worksheet tab entitled "Requirements and Objectives", the user can enter derived context specific criteria. There is capacity for forty criteria. Table 1 describes twenty performance criteria that are in the workbook for the Ft. Belvoir case study. Relative importance weights are placed on the criteria in the right hand column by *ronking* the requirements or criteria. These rankings are converted to weights and used to aggregate performance and compare the alternatives. The qualitative ranks are "essential", "critical", and "routine". Ten of the criteria or requirements from the Ft. Belvoir case are ranked as essen*tiol*, five are ranked as *criticol*, and five are ranked as *routine*. The criteria or requirements can be removed or replaced by typing over the name of the criterion or by setting the ranking to *blonk* or "not relevant".

An important aim of this effort is making the instructions of the software workbook tool understandable to the users. To make the workbook user-friendly, we match the terminology in the methodology, workbook tool, and case study to that used by stakeholders. In particular, the criteria in the workbook are referred to as *requirement*s, and rather than eliciting criteria weights, the users are prompted to *ronk* the requirements as e*ssentiol, criticol, or routine*. In this report, we will use the terms "criteria" and "requirements" interchangeably as well as the terms "weight" and "rank".

Table 1. A set of twenty performance criteria that are used to compare energy security alternatives in the Ft. Belvoir case study. The criteria are also called requirements in this report. The criteria are named in the left column, described in the middle column, and ranked or weighted according to mission criticality in the far right column.

Requirement	Descriptions	Ranking
R1. Backup power	On-site backup power units that start up when primary power is disrupted	Essential
R2. Ridethrough backup	Back-up power that is on instantaneously in the event of a disruption to primary power	Essential
R3. Reduce vulnerability to physical threats	Storms, fires, floods, earthquakes, accidents, terrorism, etc.	Essential
R4. Reduce vulnerability to non-physical threats	Cyber attacks, etc.	Essential
R5. Blackstart capabilities	Backup power that can start up and run without any power to the site	Routine
R6. Accommodate variety of science and other tenants	Science tenants have very specific power reliability and power quality needs	Critical
R7. Constant frequency	Frequency levels are crucial to many safety systems for operations such as science experiments	Essential
R8. Flexible islanding capability	System can operate in an islanded, or asynchronous mode, and selects the mode automatically	Critical
R9. Improved energy efficiency	Reduced energy consumption levels to provide the same amount of energy service	Critical
R10. Outage detectability	System checks for outages and reports those outages back to central operations	Routine
R11. Increase autonomous energy	Generating energy/power on-site	Routine
R12. Workplace safety	Power supply insures workers can do there job	Essential
R13. Decrease emissions	Reduction in any emissions (CO2, Hazardous Air Polutant amissions as defined by EPA)	Critical
R14. Increase renewables electricity production	Solar, solid waste, wind, biomass	Essential
R15. Increase renewables thermal energy production	Waste heat scavenging, passive geothermal	Critical
R16. Reduce electrical demand	Reductions in electrical demand through change in equipment, new technology, or change in process	Essential
R17. Reduce thermal demand	Reductions in thermal demand through change in equipment, new technology, or change in process	Essential
R18. Reduce water consumption/waste	Utilizing any technology/change in process that reduces water consumption	Essential
R19. Reduce solid waste to landfill	Process and technology change could yield reductions in solid waste by changing fuel type.	Routine
R20. Reduce liquid waste	Liquid waste reductions caused by changing process, technology or equipment	Routine

4. Conceptual design alternatives

This section describes the purpose and systematic approach for identifying and evaluating conceptual design alternatives of energy strategies and technologies that aid in achieving energy security goals and objectives as well as how these principles are applied in the software workbook tool, *Energy Security: A Project Selection Tool.*

4.1 Purpose

The purpose of this step of the methodology is to provide the user with a taxonomy for structuring the selection of conceptual design alternatives and a method for evaluating the alternatives against multiple performance criteria.

4.2 Systematic approach for identifying conceptual design alternatives

We begin by leveraging previously considered alternatives to inspire the consideration of various energy technologies and sources for the installation. We present a taxonomy for structuring the selection of the alternatives. From this taxonomy, energy security managers are better able to select alternatives with full consideration to all feasible alternatives within described constraints.

Here we outline both the constraints and different perspectives that are necessary to define specific alternatives to be evaluated. We present the approach for defining alternatives that will be used with energy managers to define the relevant alternatives for specific missions and operations. A systems-based approach is important when defining the alternatives (NREL, 2009). When selecting different investment alternatives, it is first necessary to determine the baseline factors and installation energy requirements[1]. These factors and requirements can serve as a benchmark and the constraints for evaluating and comparing the newly derived alternatives. The steps to identifying the criteria and requirements include the following:

- Identify essential[2]/critical[3] energy mission[4] and operations[5]
- Identify alternatives that have already been implemented on the installation

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[1] **Military requirement** — (*) An established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions, or tasks. Also called **operational requirement**.; See JP 1-02 "military requirement."

[2] **Essential task** — In the context of joint operation planning, a specified or implied task that an organization must perform to accomplish the mission. An essential task is typically included in the mission statement. See also **implied task; specified task**. (JP 5-0); See JP 1-02 "essential task."

[3] **Critical asset** — A specific entity that is of such extraordinary importance that its incapacitation or destruction would have a very serious, debilitating effect on the ability of a nation to continue to function effectively. (JP 3-07.2); See JP 1-02; "critical asset."

[4] **Mission** — 1. The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore.; See JP 1-02 "mission."

[5] **Operation** — 1. A military action or the carrying out of a strategic, operational, tactical, service, training, or administrative military mission. 2. The process of carrying on combat, including movement, supply, attack, defense, and maneuvers needed to gain the objectives of any battle or campaign.; See JP 1-02 "operation."

- Identify energy alternative programs that have been studied or otherwise assessed for implementation at the installation
- Characterize the energy security impacts of the above programs
- Identify baseline installation energy usage (total)
- Identify baseline installation energy sources
    - Grid (kWh)
    - Off Grid (kWh)
    - Imported (kWh)
    - Back Up (kWh)
- Identify baseline operations energy requirements
- Identify baseline essential/critical mission energy requirements
- Identify baseline operations energy sources
    - Grid (kWh)
    - Off Grid (kWh)
    - Imported (kWh)
    - Back Up (kWh)
- Identify baseline essential/critical mission energy sources
    - Grid (kWh)
    - Off Grid (kWh)
    - Imported (kWh)
    - Back Up (kWh)

It is then necessary to determine the percentage of energy dedicated to operations or critical/essential missions and determine percentage of energy deriving from off installation sources such as the grid, and of that, the percent that are imported. Another constraint includes whether kWh production on installation site is permitted under current memorandums of understanding (MOUs).

It is important to acknowledge that there is no one-size-fits-all list of alternatives and only through considering multiple perspectives or dimensions can a list of feasible alternatives be developed and evaluated. The taxonomy of perspectives serves as means for structuring and identifying the different investment alternatives. Considering alternatives that span all perspectives helps ensure that potentially promising alternatives are not overlooked. These dimensions along which we define the alternatives include the following:

- Missions (Deployments, base/installation security, information, analysis, …)
- Functions/Operations (Manufacturing, personnel, computing, …)
- Source/Generation (Coal, gas, diesel, solar, geothermal, …)
- Storage (Fuel cell, battery, capacitor, fuel, kinetics, superconducting, …)
- Transmission (Grid, microgrid, fixed, moveable, …)
- Control/Management (Switches, control centers, logic/algorithms, …)
- Demand reduction (HVAC, passive solar, electronics, high efficiency, …)
- Time horizons (Seconds/milliseconds, minutes, hours, days, weeks, months, …)

- Facilities (Buildings, floors, offices, laboratories, vehicles, equipment, ...)
- Partners/stakeholders (Industry, utilities, ...)
- Regional and co-located installations (Other installations, ...)
- Others

In the list above, there are sample classes of alternatives in parentheses. For example, the different source/generation types include coal, gas, etc. The different levels of facilities include entire buildings, floors, and laboratories. Through consideration of the taxonomy of perspectives, engineers work with the energy managers and stakeholders to describe the exact alternatives that are feasible throughout the project. For example, Figure 4 displays the perspective of the different facilities in the Area 300 that must be considered. Once the perspectives are considered, a feasible alternative in this case might be a microgrid with distributed generation. Figure 5 displays this alternative (with specific technical and feasibility requirements) for the different buildings.

Figure 4. The Area 300 buildings that are being considered for implementing alternatives for energy security investments.
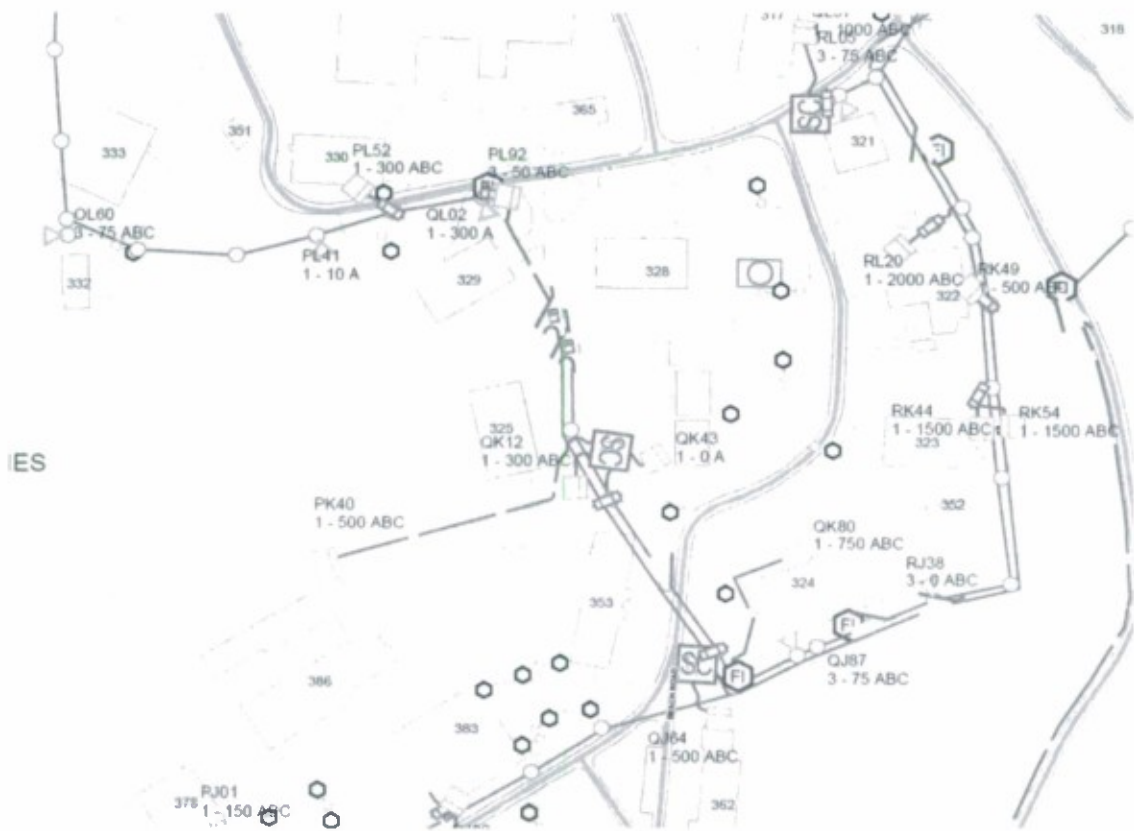
Figure 5. Example of a microgrid that considers the facilities and other perspectives.

4.3 Analysis of conceptual design alternatives in a software workbook tool

The software workbook tool, *Energy Security: A Project Selection Tool*, assists the user in the development and assessment of conceptual designs through three worksheet tabs. The investment alternatives appear in the worksheet tab labeled "Conceptual Design Build". From a taxonomy encouraging the multiple perspectives, energy security managers and other stakeholders are advised on how to build and select alternatives. Table 2 displays the inputs from the tool for building different design alternatives. The categories of consideration describe generation equipment, operational mode, size, renewable energy, supplemental equipment, strategies/technologies, and others. From this, users name each conceptual design alternative and provide a detailed description of each alternative. To build an alternative, enter the name of the alternative in the left-hand column and select properties using the pull-down menus, or enter the description in the far right column labeled "Additional Description".

The workbook tool has capacity for forty conceptual design alternatives. Once all design alternatives are entered, any subset of alternatives can be selected using the check boxes to be evaluated together for the purpose of comparing the alternatives of the subset.

Table 2 displays a list of five of the eight case study alternatives in the software. The first four of the alternatives produce 1MW of electricity. The first six alternatives use natural gas to power a microturbine. Five of the eight alternatives include some sort of renewable (described in the *additional description* column), while four of the eight include controls. These eight alternatives will be evaluated using multiple performance criteria that describe the mission and operational requirements.

Next, on the worksheet tab entitled "Design Assessment", the conceptual design alternatives are evaluated on the performance criteria. The inputs are elicited in a survey approach using qualitative inputs. Table 3 describes how the conceptual designs alternatives for the Ft. Belvoir case study are evaluated across the performance criteria. The entries on the matrix reflect the degree to which the conceptual design on top of the column address the performance criterion of the row. The user answers the question of whether a conceptual design alternative addresses a criterion with the inputs "strongly agree", "agree", "somewhat agree", and blank for no agreement. The best-performing alternative in each criterion should receive an input of "strongly agree", and the worst-performing alternative should receive an input of "disagree", or blank.

These qualitative design assessments of Table 3 along with the rankings of the performance criteria in Table 1 are converted to mathematical inputs in the workbook tool and aggregated to compare the conceptual designs. The results of this aggregation are presented in the worksheet tab entitled "Design Summary" which displays the conceptual designs rankings relative to each other as shown in Figure 6.

Table 2. Example of how five of the eight conceptual design alternatives appear in the software workbook tool *Energy Security: A Project Selection Tool.* Instructions are provided for describing each conceptual design alternative and sufficient room is given to give a full description of the alternative. These conceptual design alternatives are to be prioritized using the performance criteria or requirements.

Conceptual Design	Include?	1 MW Microturbine	Reciprocating engine with generator Electricity only	Waste heat capture	Primary power	Backup power	Renewable	Natural gas	Oil	Bio-gas	Synthetic gas	Solar PV	Solar thermal	Wind	Waste-to-energy	Geothermal	New comfort conditioning equipment Heat pump	Boiler	Air conditioning (DX units) Condenser	Fans	Blowers	Heat exchanger	Building efficiency improvements	Backup flywheel and clutch	Controls and automation	Waste heat capture	Monitoring and comparison	Waste heat scavenging	Metering/submetering	Selling excess back	Efficiency analysis	Additional Description
Ft. Belvoir NVESD 300 Area Phase I A	✓	1		x				x															x									• tbd
Ft. Belvoir NVESD 300 Area Phase IB	✓	1		x				x															x	x		x		x		x		• tbd
Ft. Belvoir NVESD 300 Area Phase IC	✓	1		x				x			x	x	x	x									x		x							• tbd
Ft. Belvoir NVESD 300 Area Phase IIA	✓	1	x					x															x									• tbd
Ft. Belvoir NVESD 300 Area Phase IIB	✓	4		x				x															x	x	x	x			x	x		• tbd

Table 3. The conceptual design alternatives are assessed across the performance criteria. T
user is asked to assess whether the alternative of the column addresses the objective of t
row criterion. The inputs are "Strongly Agree", "Agree", "Somewhat Agree", "Disagree"
blank for no agreement.

Requirements (from Requirements and Objectives tab)	Ft. Belvoir NVESD 300 Area Phase IA	Ft. Belvoir NVESD 300 Area Phase IB	Ft. Belvoir NVESD 300 Area Phase IC	Ft. Belvoir NVESD 300 Area Phase IIA	Ft. Belvoir NVESD 300 Area Phase IIB	Ft. Belvoir NVESD 300 Area Phase IIC	Ft. Belvoir NVESD 300 Area Phase IID	Ft. Belvoir NVESD 300 Are...
R1. Backup power is achieved by this conceptual design.	Agree	Agree	Agree		Agree	Agree	Agree	Agre
R2. Ridethrough backup is achieved by this conceptual design.	Agree	Agree	Agree		Agree	Agree	Agree	Agre
R3. Reduce vulnerability to physical threats is achieved by this conceptual design.	Agree	Agree	Agree	Somewhat Agree	Agree	Agree	Agree	
R4. Reduce vulnerability to non-physical threats is achieved by this conceptual design.	Strongly Agree	Strongly Agree	Strongly Agree		Strongly Agree	Strongly Agree	Strongly Agree	Stron
R5. Blackstart capabilities is achieved by this conceptual design.	Somewhat Agree	Agree	Somewhat Agree		Agree	Somewhat Agree	Somewhat Agree	Some
R6. Accommodate variety of sciences and other tenants is achieved by this conceptual design.	Somewhat Agree	Agree	Somewhat Agree		Agree	Somewhat Agree	Somewhat Agree	Som
R7. Constant frequency is achieved by this conceptual design.	Agree	Agree	Agree	Somewhat Agree	Agree	Agree	Agree	
R8. Flexible islanding capability is achieved by this conceptual design.	Somewhat Agree	Somewhat Agree	Somewhat Agree		Agree	Somewhat Agree	Strongly Agree	Stron
R9. Improved energy efficiency is achieved by this conceptual design.		Agree			Agree		Strongly Agree	Stron
R10. Outage detectability is achieved by this conceptual design.		Somewhat Agree			Somewhat Agree		Strongly Agree	Stron
R11. Increase autonomous energy is achieved by this conceptual design.	Somewhat Agree	Somewhat Agree	Agree	Agree	Agree	Agree	Strongly Agree	Stron
R12. Workplace safety is achieved by this conceptual design.		Somewhat Agree			Somewhat Agree		Somewhat Agree	Some
R13. Decrease emissions is achieved by this conceptual design.	Somewhat Agree	Somewhat Agree	Agree	Agree	Agree	Agree	Strongly Agree	Stron
R14. Increase renewables electricity production is achieved by this conceptual design.			Strongly Agree			Strongly Agree	Strongly Agree	Stron
R15. Increase renewables thermal energy production is achieved by this conceptual design.			Strongly Agree			Strongly Agree	Strongly Agree	Stron
R16. Reduce electrical demand is achieved by this conceptual design.		Agree			Agree		Agree	Agre
R17. Reduce thermal demand is achieved by this conceptual design.		Agree			Agree		Agree	Agre
R18. Reduce water consumption/waste is achieved by this conceptual design.				Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Stron
R19. Reduce solid waste to landfill is achieved by this conceptual design.								
R20. Reduce liquid waste is achieved by this conceptual design.								

	Ft. Belvoir NVESD 300 Area Phase I A	Ft. Belvoir NVESD 300 Area Phase IB	Ft. Belvoir NVESD 300 Area Phase IC	Ft. Belvoir NVESD 300 Area Phase IIA	Ft. Belvoir NVESD 300 Area Phase IIB	Ft. Belvoir NVESD 300 Area Phase IIC	Ft. Belvoir NVESD 300 Area Phase IID	Ft. Belvoir NVESD 300 Area Phase IIE
Baseline Score	33	50	45	16	61	54	74	74
Baseline Ranking	7th	5th	6th	8th	3rd	4th	1st	1st

Figure 6. The summary of results of the multicriteria assessment that compares several conceptual designs for energy security.

5. Scenarios of emergent conditions

This section describes the purpose and systematic approach for identifying relevant scenarios of emergent and future conditions that likely influence energy security decisions as well as how these principles are applied in the software workbook tool, *Energy Security: A Project Selection Tool.*

5.1 Purpose

Integration of emergent conditions provides a measure for robustness of the prioritization of conceptual design alternatives. An emergent or future condition is an event or trend that could occur over the considered timeframe and whose occurrence could affect how decisions are made or energy security program alternatives are prioritized (Karvetski et al., 2011a, 2011b, 2009). Throughout this report, these emergent or future conditions are referred to as just emergent conditions, or, when clear, just conditions. Energy managers must address these emergent conditions in addition to the multiple objectives related to integrating multiple fuel sources, reducing energy consumption, reducing foreign energy inputs, and integrating renewable resources. The life cycle timeframe referenced here is typically a few decades, so future regulations, energy availabilities, technology advances, geopolitical events, catastrophic weather and destructive events, and other conditions pose uncertainty and sources of risk in the decision making. The scenarios of emergent conditions are used to generate a new weighting of the performance criteria, which is used along with the assessments of the conceptual designs across the criteria to generate a new comparison of the alternatives for each scenario.

5.2 Systematic process for identifying emergent and future conditions

Combining future geographic, regulatory, geopolitical, environmental, and other emergent conditions results in diverse future scenarios or combinations of conditions (Tonn et al., 2009; United Nations, 2008; World Energy Council, 2007; Mintzer, 2003; Nakićenović, 2000). These combinations are used to test the robustness of the conceptual design alternatives. For an installation such as Ft. Belvoir, the emergent conditions can include local, regional, national, and international conditions. Regulatory and political changes represent a significant class of emergent conditions. Emergent conditions from this class include new energy guidelines and incentives. Some examples include future carbon legislation, renewable energy credits, and different regulatory pricing structures.

National and international technology-related emergent conditions include immediate, unforeseen shifts in energy technologies related to new nuclear technologies or promising renewable energy technologies. International conditions include shifts in the geopolitical power relating to different fuels including natural gas, which is the main fuel source typically used to run the microturbines proposed by the case study at Ft. Belvoir. The emergent conditions influence availability and costs of these energies. Conditions at the installation that can impact mission execution include local disruption of energy services caused by commercial energy grid failures, destruction of energy systems or terrorism, and deterioration of other interconnected infrastructures. Other conditions involve weather and climate, fuel and material supply chains, institutional and organizational issues, and changing security requirements.

This section describes two structured and repeatable processes for identifying relevant emergent conditions for an installation. Both approaches motivate energy managers and stakeholders to think holistically to identify a comprehensive set of emergent conditions. The first approach is Hierarchical Holographic Modeling (HHM; Haimes, 2009). The idea of the HHM is to view the investment decision and the future through multiple perspectives to identify the relevant emergent conditions for each perspective. The second approach is to identify relevant emergent conditions as they pertain to the steps of the systems lifecycle.
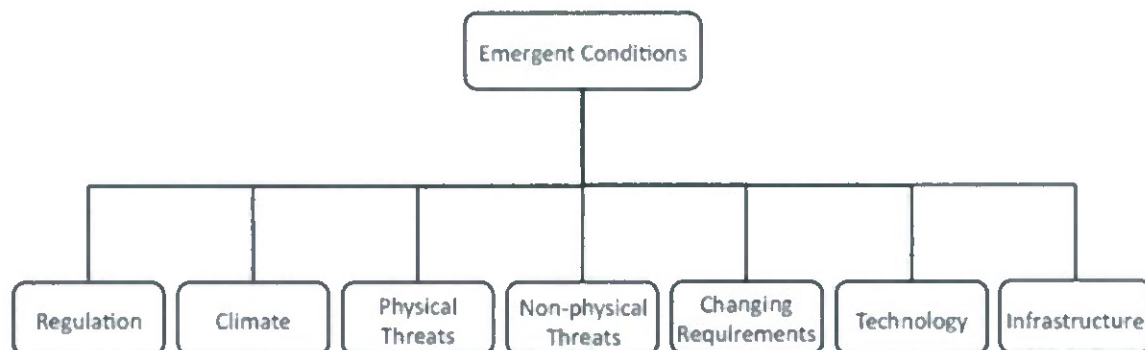
Figure 7. Example of Ft. Belvoir 300 Area hierarchical holographic model for identifying emergent and future conditions that can influence energy security of the installation.

Figure 7 describes an HHM for decomposing energy security emergent conditions into a set of seven categories, which are defined as *headtopics*. For each headtopic, the individual emergent conditions are identified. For example, stakeholders may first start with cataloging all possible emergent conditions that could be disturbing to priority setting from a regulatory perspective. These could include different pricing structures, renewable portfolio standards, and others. Analyzing the same decision with regards to upsetting climate conditions would reveal

winter storms and changing temperature patterns as two emergent conditions for the *Climate* headtopic.

Some emergent conditions can correspond to multiple headtopics. For example, an ice or other powerful storm could result in trees falling on exposed lines. This emergent condition could therefore correspond to the *Climate* and *Physical Threats* headtopics. Other emergent conditions under *Physical Threats* include intentional attacks on the energy system. Examples of non-physical threats include cyber attacks. For *Changing Requirements*, examples of emergent conditions include changing tenant and other building requirements or changes in business cases. Advances in the performances of different technologies and failing energy and other interconnected infrastructures represent emergent conditions for the respective headtopics *Technology* and *Infrastructure*.

Another way to identify relevant emergent conditions is through the viewpoint of the systems life cycle. Figure 8 describes a set of emergent conditions as they relate to eight phases of the systems lifecycle. The lifecycle begins with a definition of the energy security goals for the installation. Relevant emergent conditions for this phase include changing high-level requirements or possibly Department of Defense campaign shifts. Next the high-level requirements are documented for the energy system. These include the buildings that need quality power and others, but different stakeholders will have different viewpoints on the exact nature of these requirements. Thus changing objectives and business cases would alter these requirements. When the formed conceptual designs can be compared across many objectives, the changing regulations could change how the designs perform relative to one another.

When the conceptual designs are specified in more detail, new advances in different technologies could change the efficiency, cost, and other performance parameters that therefore change the desirability of the technologies. When the energy system is constructed and tested, changing building requirements may change the feasibility of different designs and weather and other physical and non-physical threats may cause performance to differ from those described in the engineering specifications. Ultimately, regulations and other possible events over the long time horizon of the energy system lifecycle could affect the sustainability and usability of the energy system.

Impact of Emergent and Future Conditions (cont.)

Changing requirements, geopolitics, threats, DoD campaign shifts, others

Changing regulations, performance degradation, legacy equipment others

Changing donor objectives, changing business cases, others

Efficacy of working-group approach, technology efficiency, others

Changing customers, climate, regulations, others

Weather events, physical threats, cyber threats, failing connected infrastructures, changing regulations, others

Advances in technologies (fuel cells, PV systems, etc.), others

Changing building requirements, infrastructure, others

Energy Security Goals

System Requirements

Sustainment

Conceptual Design

Performance Evaluation

Energy Security System Lifecycle

Testing/ Monitoring
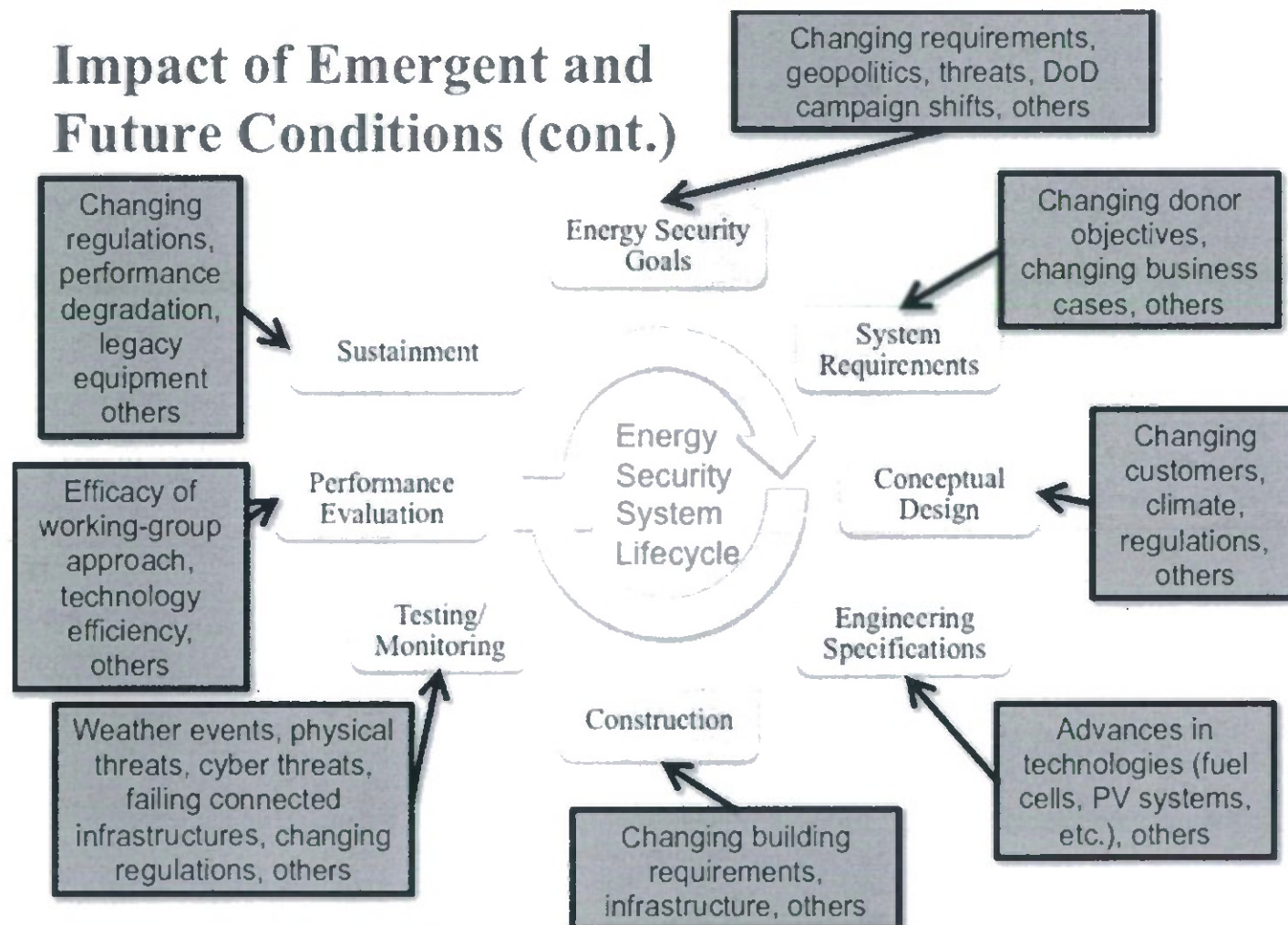
Engineering Specifications

Construction

Figure 8. Emergent and future conditions can be combined to form scenarios that test the robustness of the prioritization of conceptual design alternatives for energy security of the installation

5.2.2 Description of Regulatory and Other Emergent Conditions

Overview

Selected emergent conditions will be discussed herein in more detail than others. T *regulatory* emergent conditions represent one very important class of emergent conditio These emergent conditions affect the cost-benefit analysis and also affect the desirability of t conceptual designs over the long time horizons. These regulatory emergent conditions requir further explanation. Here, we describe these emergent conditions.

Renewable portfolio standards (RPS)

A renewable portfolio standard is a state policy that requires electricity providers obtain a minimum percentage of their power from renewable energy resources by a cert date (DOE, 2010). Virginia currently has a voluntary renewable energy portfolio standard. T goal is to have 15% (relative to 2007 base year) of energy come from renewable sources 202S. The eligible energy resources include solar, wind, geothermal, hydropower, wave, tid and biomass energy. Onshore wind and solar power receive a double credit toward RPS go and offshore wind receives triple credit. Electricity must be generated or purchased in Virgi or in the interconnection region of the regional transmission entity (DSIRE, 2010). A change these requirements could affect how and when Ft. Belvoir and other similar installations wo integrate renewable sources into a potential energy-security plan.

Time of day pricing

Time of day pricing is a pricing structure that delivers energy during nonpeak times a discounted rate. During peak times, utility companies need to start up generators that are m costly to run. Virginia has previously piloted a time of day pricing program in 2007 (Rein, 2007)

Output-based environmental regulations

Output based regulations help encourage innovative and energy efficient products s as combined heat and power (CHP) by relating emissions to the productive output of t process rather than the amount of fuel burned. While input based regulations establish lir based on heat input (e.g, lbs/MMbtu) or exhaust concentration in the exhaust stream, outr based regulations establish limits based on the emissions per unit of useful energy outr (lbs/MWh). Output-based emission limits account for the emission reduction benefits of ene efficiency, thus making it more attractive for regulated sources to install clean ene technologies. Output-based regulatory concepts can be applied to a variety of air regulat programs, including:
- Conventional emission limits
- Emission limits for small DG and CHP
- Allowance allocation in emission trading programs
- Allowance allocation set-asides for energy efficiency and renewable energy

So far, twelve states have established one or more of these of output-based regulatio Virginia has not currently implemented output-based regulations (U.S. EPA, 2010).

Performance-based rates

Regulators in some states are creating proposals to decouple utility profits from sales volume in order to promote energy efficiency and distributed generation. Traditional regulatory approaches tie a utility's profits to the volume of electricity or gas sold via the ratemaking structure. Performance-based rates thus provide a disincentive to invest in cost-effective demand-side resources that reduce sales. If utility profits are decoupled from sales volumes in such a way to ensure the utilities can recover their fixed and variable costs, it will allow for a fair, economically-based comparison between supply and demand-side resource alternatives. One example of performance based ratemaking is to allow more frequent true-ups to rates to reflect actual sales and actual fixed cost revenue requirements (U.S EPA, 2006).

Exit fees

Under traditional utility rate making structures, when facilities reduce or end their use of electricity from the grid through distributed generation or efficiency technologies, they reduce the utility's revenues that cover fixed costs on the system. The remaining customers may ultimately have to bear these costs. This can be a problem if a large customer such as a military installation leaves a small electric system. States that have restructured their electric utility may allow utilities to charge an exit fees on the departing load to avoid shifting the revenue responsibility for those costs to the remaining customers. As this may serve as a disincentive for distributed generation, some states are exploring whether other methods exist to help utilities recover their sunk fixed costs. Some states have exempted CHP and renewable projects from these exit fees to recognize the economic value of these projects, including their grid congestion relief and reliability enhancement benefits (U.S. EPA, 2006).

Standby rates

Facilities that use distributed generation such as renewables or CHP usually need standby power for when the system is unavailable due to equipment failure, maintenance, or other outages. Electric utilities often assess standby charges to onsite generation to cover the additional costs they incur as they continue to provide adequate generating, transmission, or distribution capacity to supply electricity to these customers when requested. The utilities must be prepared to serve the unexpected load under extreme conditions such as a peak demand period. However, the probability all interconnected small-scale distributed generation will need standby power at the same high peak demand time is very low. Furthermore, these standby rates may hinder the economics of distributed clean and renewable generation, and, consequently, states are exploring alternatives to standby rates that may more accurately reflect these conditions and value the benefits that CHP and renewables provide to the electric system (U.S. EPA, 2006).

Buyback rates & net metering regulations

The ability for selling excess electricity from renewable and CHP projects back to the grid is often a critical component of the economic feasibility of distributed generation projects. The price that utilities offer for purchasing excess electricity can vary widely and is affected by federal and state requirements. The Public Utilities Regulatory Policy Act (PURPA) sets standards for buyback rates at the utility's avoided cost (i.e., the cost of the next generating resource available to the utilities). However, some net metering regulations allow small generators (typically renewable energy up to 100 kW) a guaranteed purchase for their excess generation at a distribution utility's retail cost (U.S. EPA, 2006).

Feed-in tariffs

Feed-in tariffs are a policy mechanism used to encourage the adoption of distributed renewable energy sources. While they are used extensively throughout Europe, so far only a few places have implemented such policies in the U.S. They help to make non-utility owned distributed energy more economically feasible by providing an obligation for electric utilities to buy the excess electricity from distributed renewable sources. Feed-in tariffs typically include three provisions: guaranteed grid access, long-term contracts (15-25 years) for the electricity, and purchase prices that are based on the cost of renewable energy generation.

5.3 Analysis of scenarios of emergent conditions in the software workbook tool

The software workbook tool, *Energy Security: A Project Selection Tool,* assists the user in the development and assessment of scenarios of emergent conditions through two worksheet tabs. The bulleted list below describes a set of emergent conditions along the left column as they appear in the worksheet tab entitled "Impact Analysis (1)". Table 4 displays this tab. Importantly, the occurrence of these conditions is not mutually exclusive and thus these conditions can be combined. The scenarios, listed across the top row of Table 4, are defined to consist of one or more emergent conditions. There is capacity for fifty emergent conditions and five combinations of conditions (scenarios). The set of conditions that may be relevant are listed as:

- Increase in cyber threats
- National Renewable Portfolio Standards (RPS)
- Electric vehicles become the focus of the "green" movement
- Carbon tax/legislation
- New environmental legislation
- Advances in fuel cell technology
- Advances in PV technology
- Advances in wind technology
- Change in nature of science tenants
- Deterioration in geopolitics and war/peace/terrorism
- Breakthrough in reformation process of synthetic fuel production
- Hydrogen focused energy sector
- Oil and gas remain available and cost-effective
- Natural gas prices cut in half
- Moderate growth in energy technology
- Natural gas prices double
- Conflict with China arises
- Moderate environmental-movement impacts
- High environmental-movement impacts
- Low national economic growth
- Moderate national economic growth
- High national economic growth
- ANWR is open for drilling
- Efficiency measures reduce demand by 20%
- Change in ESPC contracts
- Biofuels prices double
- Biofuels prices cut in half
- Early realization of climate change
- Increased volatility of gas/oil prices
- Increased exposure to nearby politicians/government officials

- Increased need for proof-of-principles
- Increased pressure to get system in place

Using this list, five scenarios are created to include in the case study for Ft. Belvoir Area 300 compound. The scenarios (of each column) are created by checking of one or more conditions of the column. Table 4 indicates the five scenarios across the top and list of a few conditions down the left column. The first scenario consists of four conditions. These five scenarios are named and include:

- *Green Movement*
    - o National Renewable Portfolio Standards (RPS)
    - o Carbon tax/legislation
    - o New environmental legislation
    - o Efficiency measures reduce demand by 20%
- *Notionol Security Perspective*
    - o Increased volatility of gas/oil prices
- *Leoder-by-Exomple*
    - o Early realization of climate change
    - o Increased exposure to nearby politicians/government officials
- *Increosed Exposure of System*
    - o Increased exposure to nearby politicians/government officials
    - o Increased need for proof-of-principles
- *Poybock Perspective*
    - o Increased pressure to get system in place

Next, the scenarios are used in the workbook to adjust the criteria rankings (those that appear in the right-hand column of Table 1; *Essentiol, Criticol, Routine*). Table 5 displays how the scenarios increase the baseline relative criteria importance or ranking. This Is done on a worksheet tab entitled "Impact Analysis (2)". For example, if the scenario *Green Movement* were to occur, it is judged by the user that criteria or requirements *R9. Improved energy efficiency* and *R14. Increose renewobles electricity production* have a *MAJOR INCREASE* in ranking or relative importance compared to the other criteria. It is also judged that the criteria *R18. Reduce woter consumption/woste* and *R19. Reduce solid woste to londfill* increase in relative importance as well, but this only a *minor increose*. These judgments are carried out for the remaining scenarios. This input generates a new weighting of the criteria, which is used along with the assessments of the conceptual designs across the criteria (Table 3) to generate a new comparison of the alternatives for the scenarios.

Table 4. Example of how the scenarios (top row) are created using conditions (left column). A check mark indicates that the condition of the row is included in the scenario of the column.

Conditions	S1. Green Movement	S2. National Security Perspective	S3. Leader-by-Example	S4. Increased exposure of system	S5. Payback perspective
Increase in cyber threats	☐	☐	☐	☐	☐
National Renewable Portfolio Standards (RPS)	☑	☐	☐	☐	☐
Electric vehicles become the focus of the "green" movement	☐	☐	☐	☐	☐
Carbon tax/legislation	☑	☐	☐	☐	☐
New environmental legislation	☑	☐	☐	☐	☐
Advances in fuel cell technology	☐	☐	☐	☐	☐
Advances in PV technology	☐	☐	☐	☐	☐
Advances in wind technology	☐	☐	☐	☐	☐
Change in nature of science tenants	☐	☐	☐	☐	☐
Deterioration in geopolitics and war/peace/terrorism	☐	☐	☐	☐	☐
Breakthrough in reformation process of synthetic fuel production	☐	☐	☐	☐	☐
Hydrogen focused energy sector	☐	☐	☐	☐	☐
Oil and gas remain available and cost-effective	☐	☐	☐	☐	☐
Natural Gas prices cut in half	☐	☐	☐	☐	☐
Moderate growth in energy technology	☐	☐	☐	☐	☐
Natural gas prices double	☐	☐	☐	☐	☐
Conflict with China arises	☐	☐	☐	☐	☐
Moderate environmental-movement impacts	☐	☐	☐	☐	☐
High environmental-movement impacts	☐	☐	☐	☐	☐
Low national economic growth	☐	☐	☐	☐	☐

Table 4. (continued from above).

	1	2	3	4	5
Moderate national economic growth	☐	☐	☐	☐	☐
High national economic growth	☐	☐	☐	☐	☐
ANWR is open for drilling	☐	☐	☐	☐	☐
Efficiency measures reduce demand by 20%	☑	☐	☐	☐	☐
Change in ESPC contracts	☐	☐	☐	☐	☐
biofuels prices double	☐	☐	☐	☐	☐
Biofuels prices cut in half	☐	☐	☐	☐	☐
Early realization of climate change	☐	☐	☑	☐	☐
Increased volatility of gas/oil prices	☐	☑	☐	☐	☐
Increased exposure to nearby politicians/government officials	☐	☐	☑	☑	☐
Increased need for proof-of-principles	☐	☐	☐	☑	☐
Increased pressure to get system in place	☐	☐	☐	☐	☑

Table 5. The scenarios of emergent conditions are found to change the relative importance of the criteria.

Requirements - Baseline Rating	S1. Green Movement	S2. National Security Perspective	S3. Leader-by-Example	S4. Increased exposure of system	S5. Payback Perspective
R1. Backup power - E					
R2. Ridethrough backup - E					
R3. Reduce vulnerability to physical threats - E					
R4. Reduce vulnerability to non-physical threats - E					
R5. Blackstart capabilities - R					
R6. Accommodate variety of science and other tenants - C					
R7. Constant frequency - E					
R8. Flexible islanding capability - C				MAJOR INCREASE	
R9. Improved energy efficiency - C	MAJOR INCREASE		MAJOR INCREASE		
R10. Outage detectability - R					
R11. Increase autonomous energy - R		MAJOR INCREASE		MAJOR INCREASE	
R12. Workplace safety - E					
R13. Decrease emissions - C			MAJOR INCREASE		
R14. Increase renewables electricity production - E	MAJOR INCREASE	MAJOR INCREASE			
R15. Increase renewables thermal energy production - C					
R16. Reduce electrical demand - E					
R17. Reduce thermal demand - E					
R18. Reduce water consumption/waste - E	minor increase				
R19. Reduce solid waste to landfill - R	minor increase				
R20. Reduce liquid waste - R					

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6. Output and Interpretation

The software workbook tool supports users to gain understanding of how the conceptual design alternatives compare among each other and which scenarios are upsetting to a prioritization among the alternatives. This output includes the rank orderings of the design alternatives using a final value score for the baseline condition (no dominating scenario) and the five scenarios. The results are presented in a worksheet entitled "Top Conceptual Designs".

This is useful for identifying *robust* alternatives, defined here as alternatives that are ranked highly in all scenarios. There could an alternative that is not ranked first in any of the scenarios, but could be ranked second best across all scenarios and thus would prove to be a robust alternative. For some alternatives, one is able to identify a scenario for which the alternative is robust in all other scenarios, but drops the ranking order for this particular scenario. This scenario is defined as a *threot* to the ne*or-robust* alternative. Similarly, *opportunitie*s can be found for an alternative that is not ranked highly in other scenarios, but ranked highly in one scenario.

Table 6 describes the eight conceptual designs ranked across the baseline and five scenarios described in the last section. Figure 9 displays these ranking sensitivities of the designs to the scenarios of emergent conditions. The diamond represents the baseline ranking for the conceptual design and the range bars extend to the highest and lowest ranking value that the conceptual design received. Some conceptual designs are robust and have shorter range bars. The scenario *Poybock Perspective* is disruptive in this case study, as it causes *FT. Belvoir NVESD 300 Areo Phose IID* to drop from being the most prioritized design to the second most prioritized design. Table 7 is an example of conclusions that can be drawn from this example.

From the output, it may be determined that the conceptual design *FT. Belvoir NVESD 300 Areo Phose IID* may be selected for further analysis and design. The user could also compare this conceptual design *with FT. Belvoir NVESD 300 Areo Phose IB* to understand how a new conceptual design alternative could be created that would be more robust and responsive to all scenarios.

Table 6. The rankings of the designs (top row) for the baseline condition and the five combinations of emergent conditions. In this small example, the alternatives labeled "Ft Belvoir NVESD 300 Area Phase IID" and "FT. Belvoir NVESD 300 Area Phase IIE" are ranked best in all but one scenario, S.S Payback Perspective. This scenario is the most influential scenario.

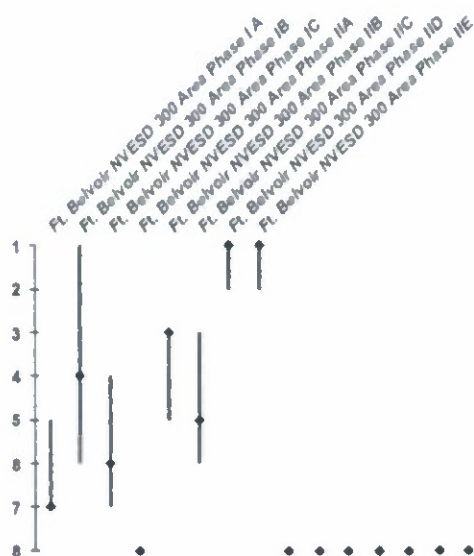|	Ft. Belvoir NVESD 300 Area Phase I A	Ft. Belvoir NVESD 300 Area Phase IB	Ft. Belvoir NVESD 300 Area Phase IC	Ft. Belvoir NVESD 300 Area Phase IIA	Ft. Belvoir NVESD 300 Area Phase IIB	Ft. Belvoir NVESD 300 Area Phase IIC	Ft. Belvoir NVESD 300 Area Phase IID	Ft. Belvoir NVESD 300 Area Phase IIE
Baseline	7th	4th	8th	8th	3rd	5th	1st	1st
S1. Green Movement	7th	8th	4th	8th	5th	3rd	1st	1st
S2. National Security Perspective	7th	8th	4th	8th	5th	3rd	1st	1st
S3. Leader-by-Example	7th	4th	8th	8th	3rd	5th	1st	1st
S4. Increased exposure of system	7th	4th	8th	8th	3rd	5th	1st	1st
S5. Payback perspective	5th	1st	7th	8th	4th	8th	2nd	2nd
Median Ranking	7th	4th	8th	8th	3rd	5th	1st	1st

Figure 9. The visual display of the ranking sensitivity for the designs. The alternatives labeled "Ft Belvoir NVESD 300 Area Phase IID" and "FT. Belvoir NVESD 300 Area Phase IIE" are ranked best in all but one scenario for which the alternatives are ranked second.

Table 7. Example output that describes the best performing designs and also the sensitivity of the designs and the most influential combinations of emergent conditions.

Enter summary notes on the results	
Best Performing Conceptual Designs	In all but the *Payback perspective* scenario, the conceptual design *FT. Belvoir NVESD 300 Aree Phese IID* is the best performing. In the *Paybeck perspective* scenario, *FT. Belvoir NVESD 300 Area Phase IB* is the best performing.
Most Influential Scenarios	The scenario *Paybeck perspective* is the most influential and upsetting, causing *FT. Belvoir NVESD 300 Area Phese IB* to be prioritized over *FT. Belvoir NVESD 300 Aree Phase IID*.

7. Stakeholder collaboration and iteration

The workbook tool is designed to evaluate conceptual design alternatives using multiple criteria or requirements and then test the sensitivity of the results using scenarios of emergent conditions. Being that the workbook is in Excel format, the workbook is easily emailed to energy managers and stakeholders. If multiple stakeholders fill the workbook out, the workbooks can be compared to understand how stakeholders agree and disagree, and where discussion needs to be focused to resolve disagreement. An additional way to get stakeholder input to populate a workbook and understand where stakeholders agree and disagree is to have them fill out the survey described in section 10, and then have stakeholders review all results.

The software workbook tool has been used in our case study for several design lifecycle phases. For example, the tool can be used very early in the design lifecycle with preliminary designs. This is demonstrated in a preliminary design workbook located at the website. In this preliminary analysis, one design (microturbine) is indicated as robust. This design is then divided into multiple alternative versions of this design, and the analysis of these multiple versions is reflected in this report.

8. Lessons learned

The methodology was tested, among other times, in a two-hour training session with three stakeholders from Ft. Belvoir NVESD Area 300. Seven preliminary design alternatives were evaluated on seven criteria. Five stakeholder scenarios were gathered from three stakeholders to test the robustness of the design alternatives. The training session is housed in a software work. With regards to the process, the stakeholders were impressed with the discussions that took place. They felt that it was important to bring together as many diverse stakeholders to

yield a broader understanding of the problem from all perspectives. This can yield more diverse, robust solution approaches. They described the potential value of using the process to filter down to subsets of alternatives and scenarios. They recommended the methods as an information gathering and processing approach for briefing higher-up officials. Other training experience is reflected in relevant conference papers, posters, and presentations, which are described in Section 12.

9. Recommendations for future effort

It is essential to support groups in strategic decision for investments in energy technologies and strategies at facilities where many, diverse stakeholders must be involved with the decision process. Decision analysis and scenario analysis tools have proved to be an effective way to engage stakeholders in productive discussion and to record and structure the information relevant to the decision environment. The structured process will help to articulate how the well the various energy systems alternatives match operational and mission requirements under a variety of emergent conditions.

Into the future, we recommend that this methodology and software workbook tool be deployed at a variety of facilities involved with energy decisions at various stages of the engineering lifecycle. The methodology encourages stakeholders to articulate all drivers that are influencing their decision-making. We suggest that a variety of stakeholders be involved in the process including representing both those who can provide scientific judgment such as technical staff and analysts, and those who can provide value judgments such as facility tenants, utility providers, the garrison commander, etc. The compiled results should be shown to higher-level decision makers to provide support and evidence for preferred energy technologies or strategies.

10. Resources for future implementation

Several resources have been developed to assist and guide the user through the methodology presented in this report. These resources are provided at the website http://www.virginia.edu/crmes/energysecurity/.

The software workbook tool entitled *Energy Security: A Project Selection Tool* is the main resource required for future implementation of the methodology presented in this report. Figure 10 displays the front page of the workbook tool. The front page gives a high-level introduction to the workbook tool and methodology. The tool supports holistic thinking about all aspects of energy security without burdening the user with excessive elicitations. The tool accepts as inputs the results of other technological, economic, and other analyses. To navigate through the workbook, the user can select the different worksheets using the tabs at the bottom of each worksheet. Instructions are provided on the top of every worksheet requiring input from the user. The second tab of the workbook tool entitled "Contacts" contains the list of the team members that designed the tool. This tab is shown in Figure 11. The project team members can be contacted to provide support to a user of the tool.

In addition to the software workbook tool, the website provides all materials for stakeholders to use the software workbook tool. The website outlines the different worksheets of the Excel workbook tool, describing both i) how the user would use each worksheet, and ii) what the current version of the case study demonstration looks like in the software tool. This workbook tool helps an energy manager and supporting stakeholders construct and evaluate multiple conceptual design alternatives. Also included is a training video that describes how to the use the software workbook tool. Also, a web-based survey is included that can be sent to the relevant stakeholders to elicit information on the modeling inputs and can show where stakeholders agree and disagree. This survey can be found at the following address: http://surveys.questionpro.com/akira/TakeSurvey?id=2405396. Appendix A provides several images from the web-based survey.

Energy Security: A Project Selection Tool

Problem Statement:
Decision making processes typically do not Include important criteria that can not be quantified. Rather, most processes rely only on "quantifiable" criteria.

Goal Statement:
The goal of this workbook is to provide a tool for installations to incorporate both qualitative and quantitative criteria into the development of an energy security plan.

Approach:
This workbook employs a survey tool to define and rank multiple criteria and requirements, in addition to future economic, political and regulatory conditions to develop robust energy security plans.

Conclusion
Using this workbook will help DOD installations make better decisions regarding project selection for Energy Plan development
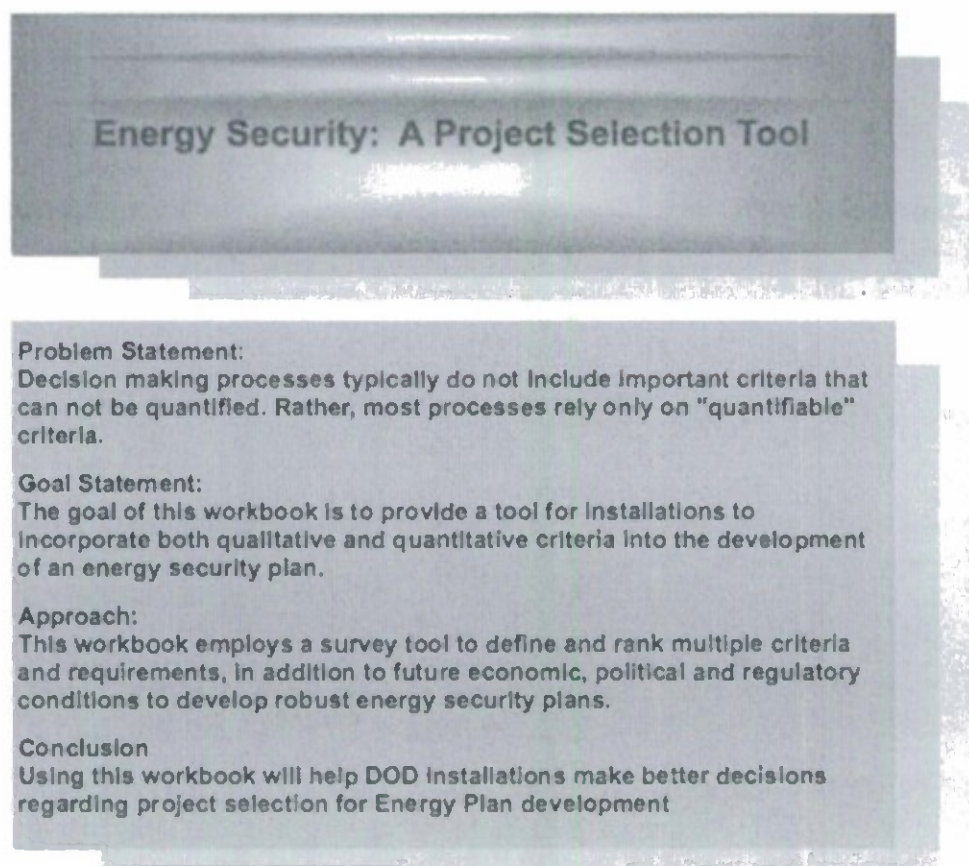
Figure 10. Introduction of software workbook tool *Energy Security: A Project Selection Tool*. This tool is developed in MS Excel to allow the tool to be mailed to energy managers and other stakeholders.

Project team

James H. Lambert
Associate Director, Center for Risk Management of Engineering Systems
Research Associate Professor
Department of Systems and Information Engineering, University of Virginia
PO Box 400747; 112C Olsson Hall, 151 Engineers Way
Office: (434) 982-2072 or (434) 531-4529
Office Manager: (434) 924-0960
Fax: (434) 924-0865
Email: Lambert@Virginia.edu

Renae D. Ditmer
President & CEO, STRATCON LLC
Belmont Bay Drive, Woodbridge, VA 22191
Office: (703) 495-5958
Cellular: (703) 989-6750
Email: renae.ditmer@stratcon.us

Jeffrey M. Keisler
Keisler Consulting, and Associate Professor of Management Science and Information Systems
College of Management, University of Massachusetts Boston
100 Morrissey Blvd., Boston, MA 02125
Office: (617) 287-7738
Email: Jeff_Keisler@hotmail.com

Chris Karvetski
PhD Graduate Student, Center for Risk Management of Engineering Systems
(434) 660-2648
cwk5b@Virginia.edu

Michelle Hamilton
PhD Graduate Student, Center for Risk Management of Engineering Systems
(717) 860-6092
mcg7w@Virginia.edu

Other contacts

ERDC Contracting Officer's Technical Representatives:
Tarek Abdallah
(217) 373-5872
t-abdellah@cecer.army.mil

Melenia Johnson
(217) 373-5872
Melenie.d.Johnson@usace.army.mil

ERDC major contributor to associated research projects:
Igor Linkov
(978) 318-8197
Igor.Linkov@usace.army.mil

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Figure 11. The contacts list of the workbook.

11. Policy documents

Below are links to following key doctrines and legislation that we have found useful for making energy security plans:

- Energy Policy Act of 2005 (http://www.epa.gov/oust/fedlaws/publ_109-058.pdf)
- Energy Independence and Security Act 2007
  (http://www1.eere.energy.gov/femp/regulations/eisa.html)
- Executive Order 13423 (http://www.fedcenter.gov/programs/eo13423/)
- Department of Defense 4170.11
  (http://www.dtic.mil/whs/directives/corres/pdf/417011p.pdf)
- Army Regulation 420-1 (http://www.army.mil/usapa/epubs/pdf/r420_1.pdf)
- Army Energy and Water Campaign Plan
  (http://army-energy.hqda.pentagon.mil/docs/AEWCampaignPlan.pdf)
- Army Energy Security Implementation Strategy (AESIS, 2009)
  (http://www.asaie.army.mil/Public/Partnerships/doc/AESIS_13JAN09_Approved 4-03-09.pdf)

12. Annotated References

Below are publications of the methodology that are directly related to this application:

Karvetski, C.W., J.H. Lambert, J.M. Keisler, and I. Linkov 2011a. Integration of decision analysis and scenario planning for coastal engineering and climate change. *Systems, Mon, ond Cybernetics Port A*, 41(1): 63-73.

Lambert, J.H., C.W. Karvetski, R.D. Ditmer, T. Abdallah, M.D. Johnson, and I. Linkov 2011. "Energy Security for Industrial and Military Installations: Emergent Conditions that Influence the Strategic Selection of Technologies" in Energy Security: International and Local Issues, Theoretical Perspectives, and Critical Energy Infrastructures. A. Gheorghe and I. Muresan, editors. Springer: Dordrecht Netherlands. Pp. 317-332.

Lambert, J.H., Karvetski, C.W., Linkov, I., Abdallah, T., Energy Security of Military and Industrial Facilities: A Scenario-Based Multiple Criteria Decision Analysis to Identify Threats and Opportunities. Proceedings from Tenth International Conference on Probabilistic Safety ·Assessment and Management (IAPSAM), Seattle, WA, June 2010.

Below are publications of the methodology for different applications:

Karvetski, C.W., J.H. Lambert, and I. Linkov 2011b. Scenario and multiple criteria decision analysis for energy and environmental security of military and industrial installations. To appear in *Integroted Environmentol Assessment ond Monogement*.

Karvetski, C.W., J.H. Lambert, J.M. Keisler, B. Sexauer, and I. Linkov 2011c. Climate change scenarios: Risk and impact analysis for Alaska coastal infrastructure. Accepted to *Internotionol Journol of Risk Assessment ond Monogement, Speciol Issue on Risk Anolysis of Criticol Infrostructures*.

Karvetski, C.W., Lambert, J.H., Linkov, I., 2009. Emergent Conditions and Multiple Criteria Analysis in Infrastructure Prioritization for Developing Countries. *Journol of Multicriterio Decision Anolysis*, 16: 12S-137.

Lambert, J.H., C.W. Karvetski, and I. Linkov 2011. Adaptation to climate change and other emergent conditions with inland and terrestrial infrastructure systems with application case studies. Adaptive Management for Climate Change. Dordrecht Netherlands: Springer, forthcoming.

Martinez, L.J., Lambert, J.H., Karvetski, C.W., 2011. Scenario-Informed Multiple Criteria Analysis for Prioritizing Investments in Electricity Capacity Expansion. To appear in *Reliobility Engineering ond System Sofety*.

Martinez L.J., J.H. Lambert, and C.W. Karvetski (2010). Public perception of the risks of liquefied gas terminals in Mexico: A prioritization of communication strategies. *Internotionol Journol of Criticol Infrostructures*. 6(4): 327-346.

Schroeder, M.J., and J.H. Lambert 2011. Scenario-based multi-criteria analysis for infrastructure policy impacts and planning. *Journol of Risk Research,* 14(2): 191-214.

Below are training experiences, presentations, and posters that have contributed to our efforts:

Hamilton, M.C., Lambert, J.H., and I. Linkov 2011. Identification prioritization and management of risks for energy system acquisitions and portfolio of assets. Presented at the Annual Meeting, Society for Risk Analysis (SRA), Charleston, SC. December 2011.

Lambert, J.H., Karvetski, C.W., Hamilton, M.C., Abdallah, T., Johnson, M.D., Ditmer, R.D., Keisler, J.M., Linkov, I., Energy security and net-zero initiatives at installations: emergent and future conditions influencing technology innovation and performance, 2011 US Army Corp of Engineers Infrastructure Systems Conference, Atlanta, GA, June 2011.

Lambert, J.H., Karvetski, C.W., Hamilton, M.C., Linkov, I., Abdallah, T., Johnson, M.D., Ditmer, R.D., Keisler, J.M., Energy security and environment at installations: emergent and future conditions influencing technology innovation and performance, IEEE International Technology Management Conference, San Jose, CA, June 2011.

Lambert, J.H., Karvetski, C.W., Hamilton, M.C., Linkov, I., Abdallah, T., Johnson, M.D., Ditmer, R.D., Keisler, J.M.,Energy security and environment at installations: emergent and future conditions influencing technology innovation and performance. The Environment, Energy Security, and Sustainability Symposium and Exhibition (E2S2), New Orleans, LA, May 2011

Lambert, J.H., Ditmer, R.D., Keisler, J.M., Karvetski, C.W., Hamilton, M.G., Two-day meeting and traingin session at University of Virginia, Charlottesville, VA, April 19-20 2011

Lambert, J.H., Karvetski, C.W., Hamilton, M.C., Linkov, I., Energy Security of Military and Industrial Systems: Multicriteria Analysis of Vulnerability to Emergent Conditions including Cyber Threats, IEEE International Systems Conference, Montreal, Canada, April, 2011.

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Lambert, J.H., Karvetski, C.W., Linkov. I., Implications for Infrastructure Systems of Emergent Conditions of Climate, Environment, and Environmental Regulation. Annual Meeting, Society of Environmental Toxicology and Chemistry (SETAC). Portland, OR. November 2010.

Lambert, J.H., Ditmer, R.D., Keisler, J.M., Karvetski, C.W., Hamilton, M.G., Presentation and training session at working group meeting in Carney's Point, NJ, August 31 2010.

Lambert, J.H., Karvetski, C.W., Linkov, I., Abdallah, T., Energy Security of Military and Industrial Facilities: A Scenario-Based Multiple Criteria Decision Analysis to Identify Threats and Opportunities. Workshop on Climate Change: Global Change and Local Adaptation, Iceland, June 2010

Linkov, I., Karvetski, C.W., Lambert, J.H., Abdallah, T., Case, M., Energy Security of Army Installations and Islanding Methodologies: A Multiple Criteria Decision Aid to Innovation with Emergent Conditions of the Energy Environment. The Environment, Energy Security, and Sustainability Symposium and Exhibition (E2S2), Denver, CO, June 2010.

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Lambert, J.H., Karvetski, C.W., Linkov, I., Abdallah, T., Energy Security of Military and Industrial Facilities: A Scenario-Based Multiple Criteria Decision Analysis to Identify Threats and Opportunities. Tenth International Conference on Probabilistic Safety Assessment and Management (IAPSAM), Seattle, WA, June 2010

Karvetski, C.W., Lambert, J.H., Linkov, I., 2009. Investments in energy security: a multiple criteria decision analysis with emergent conditions of the energy environment. Annual Meeting, Society for Risk Analysis (SRA), Baltimore, MD. December 2009.

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    09.pdf (Accessed May 9, 2010).
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    <http://www.worldenergy.org/documents/scenarios_study_online.pdf> (Accessed
    September 10, 2009)

Appendix A. Web-based survey to elicit stakeholder input to the software workbook tool
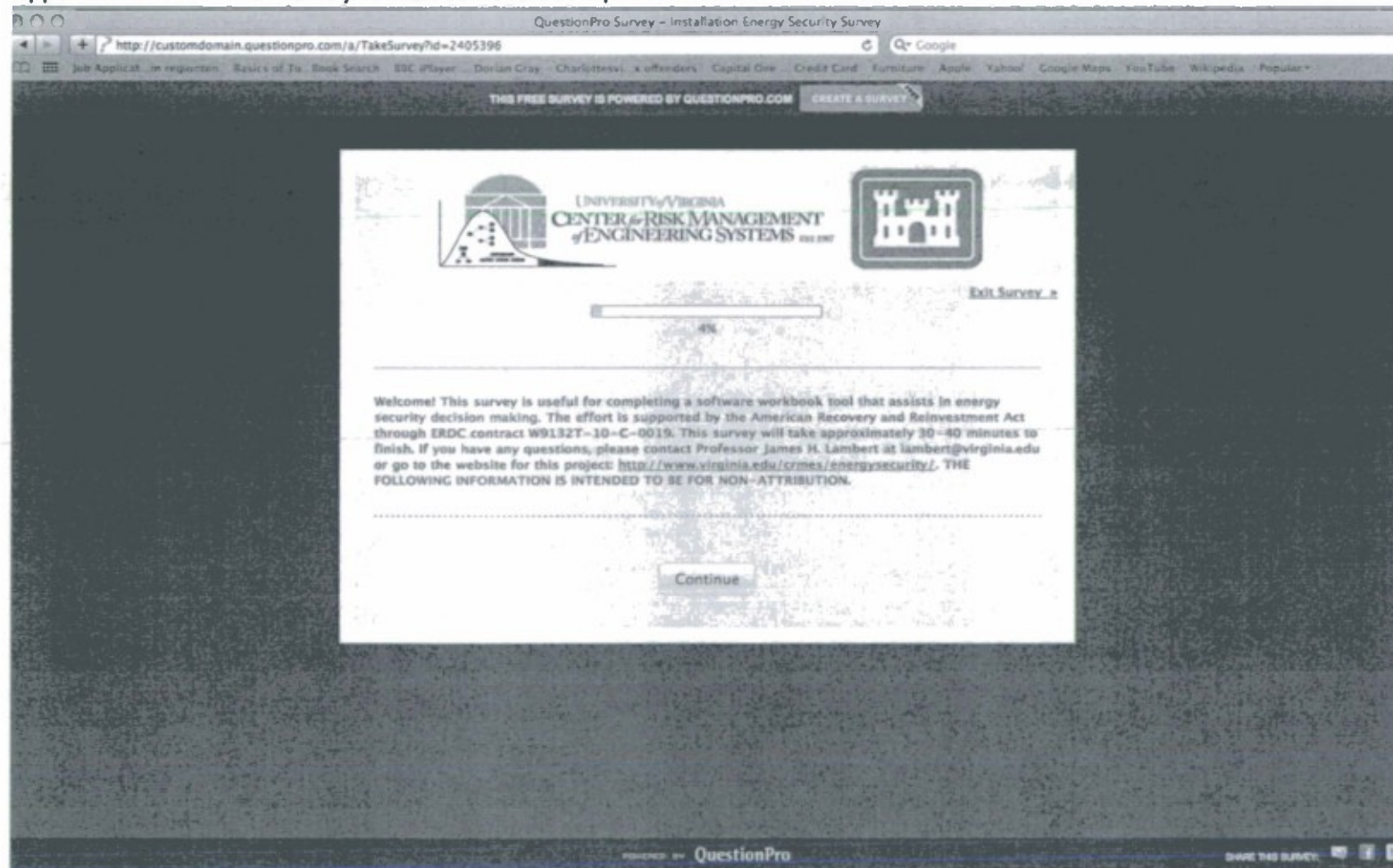
Figure 12. Introduction page of the survey website: http://surveys.questionpro.com/akira/TakeSurvey?id=2405396

Figure 13. Example question from the survey website eliciting performance criteria
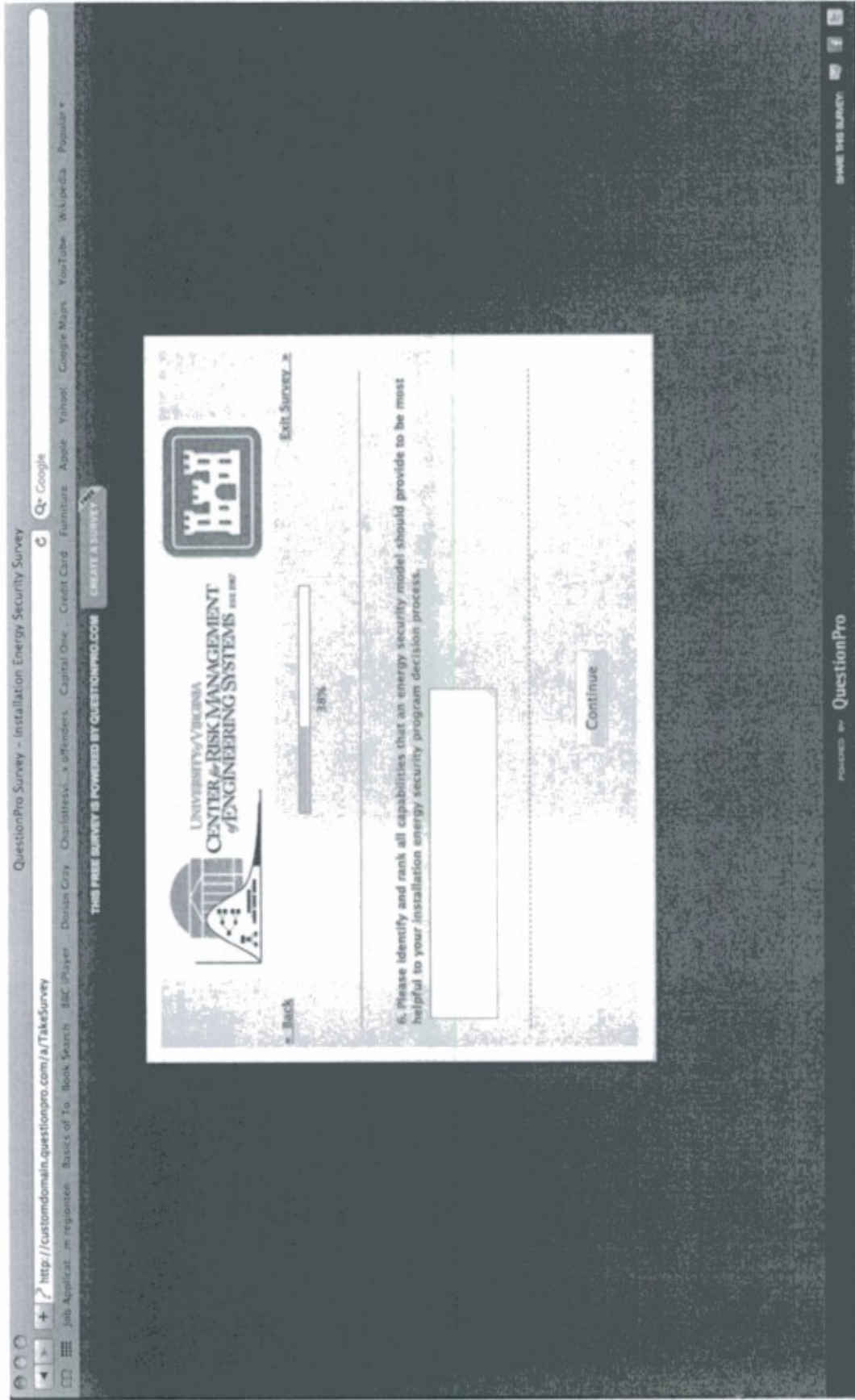
Figure 14. Example question from the survey website eliciting capability criteria

Appendix B. Website for the software workbook tool and training materials

http://www.virginia.edu/crmes/energysecurity/ | C | Q Google

Job Applicat... m regionten   Basics of To... Book Search   BBC iPlayer   Dorian Gray   Charlottesvi... x offenders   Capital One   Credit Card   Furniture   Apple   Yahoo!   Google Maps   YouTube   Wikipedia   Popular
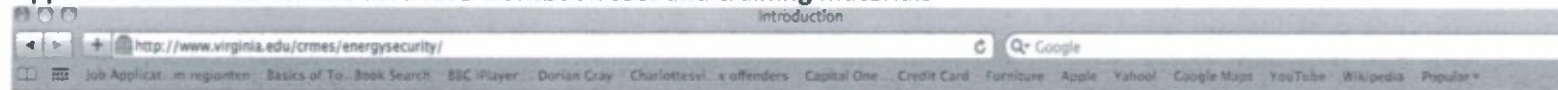
Introduction

This website contains materials for an energy security assessment software tool. The materials are the result of an effort that is supported by the American Recovery and Reinvestment Act through ERDC contract W9132T-10-C-0019. The webpage links below display the various tabs of the assessment tool, which is in Microsoft Excel format. The complete instructions for the tool can be downloaded in the following report (post link to attached technical report here). A video that describes the tool and a supporting survey for populating the tool are also included on this introduction page. The tool itself is presented in three files. Two of the files present different case studies, with one file presenting a preliminary design phase, and another file presenting a more advanced design phase of a microturbine technology. The third file presents a clean or blank tool to be populated for a new case study.

1. Introduction	2. Contacts	3. Table of Contents	4. Energy Security Goals	5. Mission-Operation
6.Requirements&Objectives	7. Conceptual Designs	8. Designs Assessment	9. Design Summary	10. Impact Analysis
11. Impact Anlysis-1	12. Impact Analysis-2	13. Results	14.Top Conceptual Designs	15. Advanced Users
16. Terms of Reference	17. Governing Documents	18. Publications		

View Video Tutorial

Download the Microsoft Excel Tool

Download the Microsoft Excel tool (preliminary design phase)

Download the Microsoft Excel tool (clean version)

Online Survey

Energy Security: A Project Selection Tool
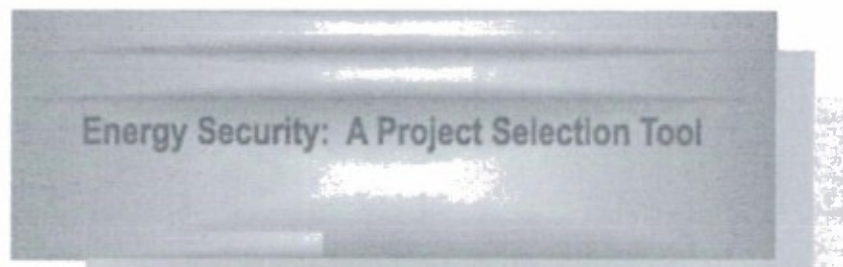
Figure 15. Introduction and table of contents of the project website: http://www.virginia.edu/crmes/energysecurity/

Energy Security of Army Installations and Islanding Methodologies: A Multiple Criteria Decision Aid to Innovation with Emergent Conditions of the Energy Environment

Principal Investigator:

James H. Lambert, Associate Director, Center for Risk Management of Engineering Systems; Research Associate Professor, Department of Systems and Information Engineering; University of Virginia, USA

Final Presentation

CONTRACT W9132T-10-C-0019

December 2011

Project Team

- James H. Lambert, P.E., Ph.D., D.WRE
  - Associate Director, Center for Risk Management of Engineering Systems Research Associate Professor Department of Systems and Information Engineering; University of Virginia
- Renae D. Ditmer, Ph.D.
  - President & CEO, STRATCON LLC
- Jeffrey M. Keisler, Ph.D.
  - Keisler Consulting, and Associate Professor of Management Science and Information Systems
- Christopher W. Karvetski, Ph.D.
  - formerly University of Virginia
- Michelle C. Hamilton
  - PhD Graduate Student, Center for Risk Management of Engineering Systems, University of Virginia

Acknowledgements

- Tarek Abdallah & Melanie Johnson, ERDC Contracting Officer's Technical Representative
- Frank Holcomb (ERDC/CERL)
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- Kevin Brady, Lead, Ft. Belvoir NVESD Energy Working Group
- Bill Elliott, Ft. Belvoir NVESD Energy Working Group
- Randy Roy, Lars Energy and Ft. Belvoir NVESD Energy Working Group

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2

Goal

Manage the emergent and future conditions that influence energy security and islanding of installations and their critical missions.

Key Questions

1) Which scenarios most and least matter to the choice of technology alternative?
2) Which investment alternatives are most and least robust to scenarios?
3) Which scenarios should be the focus of gaining further knowledge and understanding?

Motivation


```
                    ┌──────────────────────┐
                    │  Emergent and Future │
                    │      Conditions      │
                    └──────────┬───────────┘
      ┌───────────┬──────────┬─┴────────┬──────────┬──────────┐
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│Regulations││ Climate ││Geopolitics││Technology│ ... │Terrorism ││Infrastructure│
└───────────┘└─────────┘└──────────┘└──────────┘└──────────┘└──────────────┘
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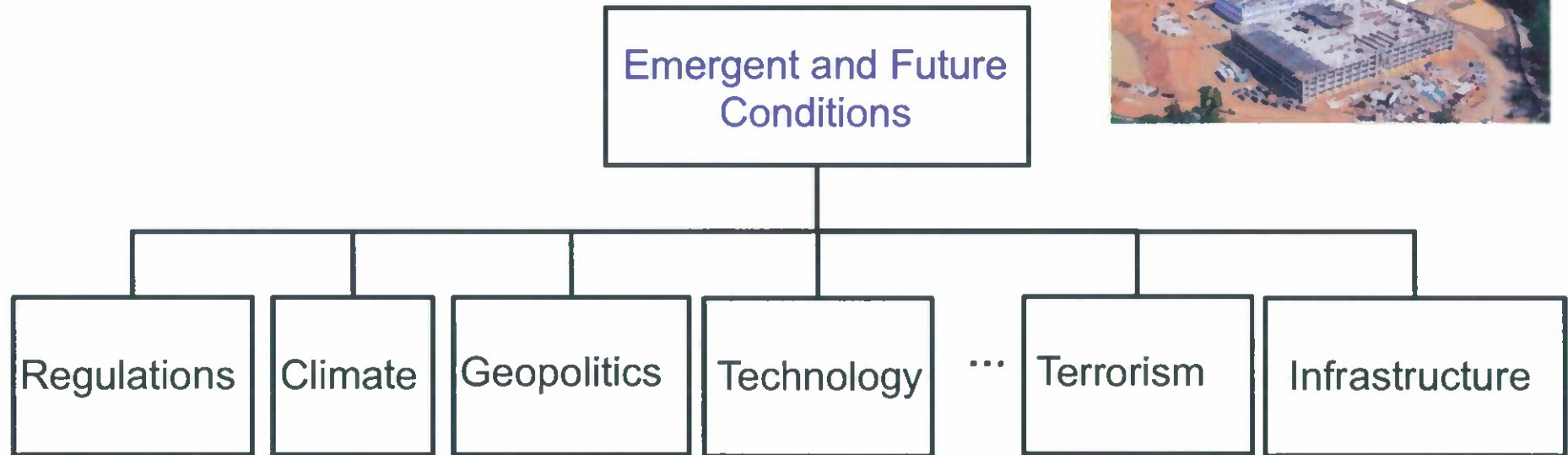
*"In an age of terrorism, combustible and explosive fuels and ...
nuclear materials create security risks. World market forces and
regional geopolitical instabilities broadly threaten energy
supplies. Infrastructure vulnerabilities pose further risks of
disruption to ... installations."*

Source: US *Army Energy and Water Campaign Plan for Installations*

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4

Motivation (cont.)

In stakeholder discussion and negotiation during preliminary engineering efforts, scenarios can emerge from stakeholders as narrative descriptions of future risks and opportunities. These scenarios need to be addressed in terms of how they affect a prioritization of decisions in order to proceed.

Approach

- Used **risk analysis and decision analysis**

- Supported an **energy security working group** at Ft. Belvoir, VA

- Assessed the impacts of **emergent and future conditions** on installation energy security

- Addressed the **alternatives, tenants/stakeholders/ requirements, and emergent conditions**

- Developed a **web-based risk and decision-analysis self-assessment tool, survey tool, and video tutorial** to support garrison commanders with energy security decision making

- Downloads available at www.virginia.edu/crmes/energysecurity

Components of Approach

- **Conceptual designs** (strategies and technologies) that improve energy security
- **Performance criteria** to compare and evaluate the alternatives
- **Emergent and future conditions** that could affect the performance of alternatives

Oil Prices, 1994–March 2008
(NYMEX Light Sweet/WTI)

Methodology

Refine the alternatives

Assess coefficients and assess alternatives on criteria

Identify energy security alternatives

Utilize multiple criteria model to prioritize alternatives

Negotiate priorities and support innovation with selected alternatives

Identify criteria/ requirements for the stakeholders

Identify emergent and future scenarios

Assess necessary coefficient shifts for each scenario

Study what scenarios most influence priority-setting

Refine the scenarios

Case Study

- **Islanding** of key functions from the grid
- Providing alternative **generation, distribution, and storage**
  - Microturbines, microgrids, combined heat and power, etc.
- Enabling use of **renewable energy sources**
  - Biomass, landfill gas, municipal solid waste, geo-thermal, solar, wind, tidal, etc.
- **Reducing consumption**
- **Improving efficiencies**
- **Monitoring/benchmarking** system performance
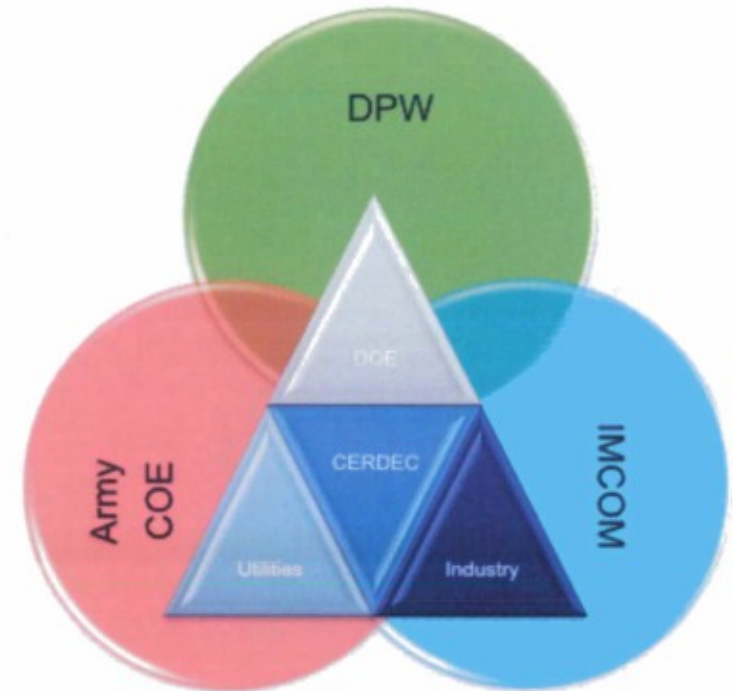
Source: *POC at Ft. Belvoir and leader of the Working Group: Mr. Kevin Brady

Ft. Belvoir Working Group

- Department of Energy (DOE)
- National Renewable Energy Laboratory (NREL)
- Sandia National Laboratory; FEMP
- Oak Ridge National Laboratory
- C2, Power Generation Branch

- IMCOM
- Installation DPW
- The University of Virginia Engineering department
- Program Manager for Mobile Electric Power

- Aberdeen Proving Ground DPW
- Dominion
- Washington Gas
- PEPCO
- GE
- Johnson Controls

Step 1. Identify Performance Criteria
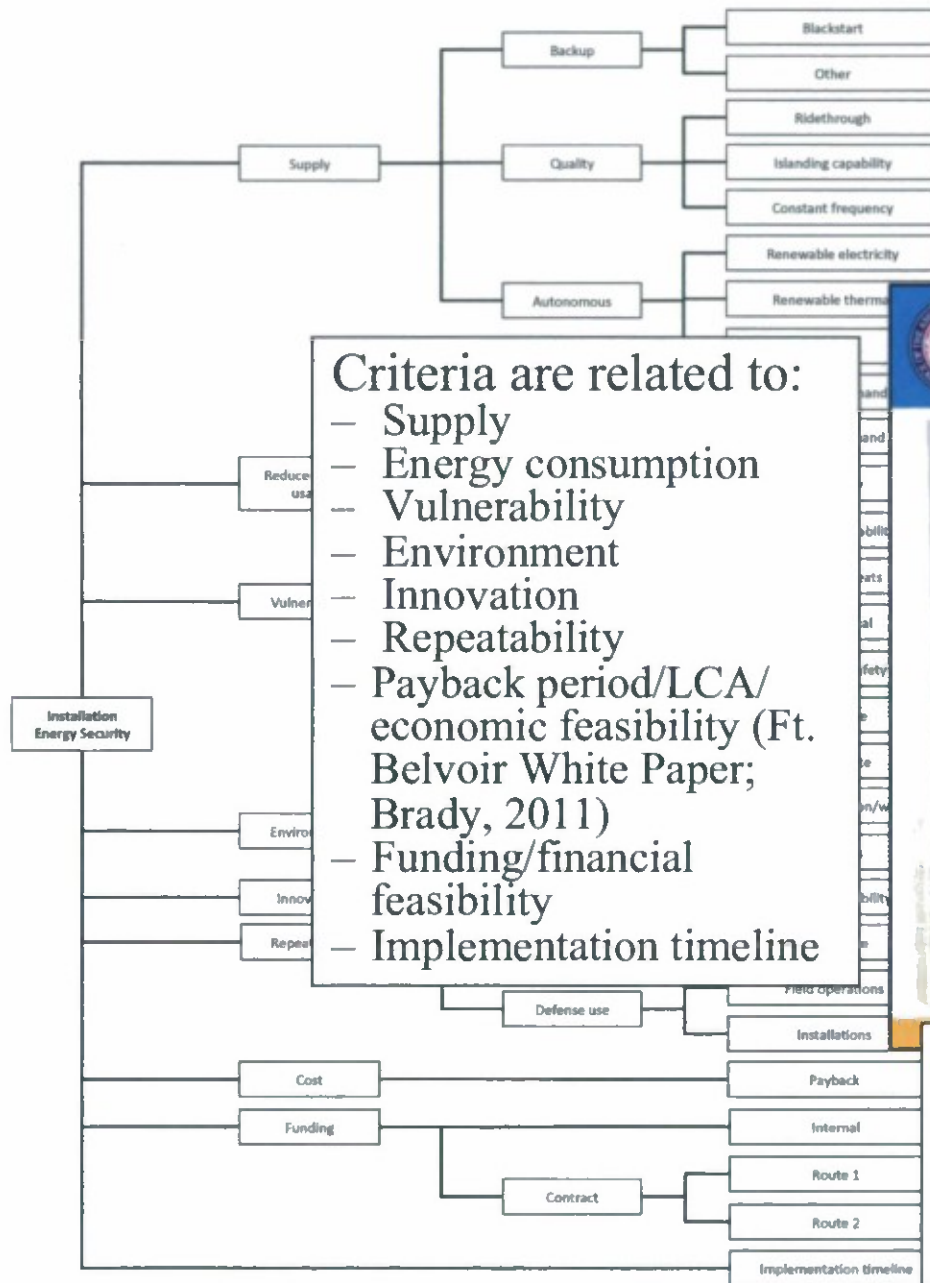
Criteria are related to:
- Supply
- Energy consumption
- Vulnerability
- Environment
- Innovation
- Repeatability
- Payback period/LCA/ economic feasibility (Ft. Belvoir White Paper; Brady, 2011)
- Funding/financial feasibility
- Implementation timeline

Sample of Agency Requirements Related to Energy Security

Source: Energy Security Program, Asst. Secretary of the Army for Installation and Environment, Kevin Geiss, Ph.D., Director

Legislation
- EPAct 2005
- EISA 2007
- NDAA 2007

Executive Order
- EO 13423

OSD Policy
- DODI 4170.11, DOD Managers Handbook

Army Policy
- Army Regulation 420-1
- Army Energy & Water Campaign Plan

Army Senior Energy Council

Energy Security Goals (ESGs)
1. Reduce Energy Consumption
2. Increase Energy Efficiency Across Platforms and Facilities
3. Increase Use of Renewable / Alternative Energy
4. Assure Access to Sufficient Energy Supplies
5. Reduce Adverse Impacts on the Environment

Performance criteria related to agency and regulatory goals and installation specific needs

Step 2. Order the Performance Criteria

Requirement	Descriptions	Ranking
R1. Backup power	On-site backup power units that start up when primary power is disrupted	Essential
R2. Ridethrough backup	Back-up power that is on instantaneously in the event of a disruption to primary power	Essential
R3.Reduce vulnerability to physical threats	Storms, fires, floods, earthquakes, accidents, terrorism, etc.	Essential
R4. Reduce vulnerability to non-physical threats	Cyber attacks, etc.	Essential
R5. Blackstart capabilities	Bac... site	Routine
R6. Accommodate variety of science and other tenants	Scie... uality nee...	Critical
R7. Constant frequency	Fre... ns such as science experiments	Essential
R8. Flexible islanding capability	System can operate in an islanded, or synchronous mode, and selects the mode automatically	Critical
R9. Improved energy efficiency	Reduced energy consumption levels to provide the same amount of energy service	Critical
R10. Outage detectability	System checks for outages and reports those outages back to central operations	Routine

Context-specific assessment of relative importance of performance criteria

Step 3. Elicit Experts on Alternatives

Conceptual designs

Assessments of conceptual designs on energy security performance criteria

Performance criteria

Requirements (from Requirements and Objectives tab)	Ft. Belvoir NVESD 300 Area Phase I A	Ft. Belvoir NVESD 300 Area Phase IB	Ft. Belvoir Area			Ft. Belvoir NVESD 300 Area Phase IID		Ft. Belvoir NVESD 300 Area Phase IID	Ft. Belvoir NVF Area Phas
R1. Backup power is achieved by this conceptual design.	Agree	Agree	Agree			Agree	Agree	Agree	Agree
R2. Ridethrough backup is achieved by this conceptual design.	Agree	Agree	Agree			Agree	Agree	Agree	Agree
R3. Reduce vulnerability to physical threats is achieved by this conceptual design.	Agree	Agree	Agree	Somewhat Agree		Agree	Agree	Agree	Agree
R4. Reduce vulnerability to non-physical threats is achieved by this conceptual design.	Strongly Agree	Strongly Agree	Strongly Agree			Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree
R5. Blackstart capabilities is achieved by this conceptual design.	Somewhat Agree	Agree							what ee
R6. Accommodate variety of science and other tenants is achieved by this conceptual design.	Somewhat Agree	Agree							what ee
R7. Constant frequency is achieved by this conceptual design.	Agree	Agree							ee
R8. Flexible is... conceptual design.	Somewhat Agree	Somewha Agree							ngly ee
R9. improved ... conceptual design.		Agree							ngly ee
R10. Outage detectability is achieved by this conceptual design.		Somewhat Agree				Somewhat Agree		Strongly Agree	Strongly Agree
R11. Increase autonomous energy is achieved by this conceptual design.	Somewhat Agree	Somewhat Agree	Agree	Agree		Agree	Agree	Strongly Agree	Strongly Agree
R12. Workplace safety is achieved by this conceptual design.		Somewhat Agree				Somewhat Agree		Somewhat Agree	Somewhat Agree
R13. Decrease emissions is achieved by this conceptual design.	Somewhat Agree	Somewhat Agree	Agree	Agree		Agree	Agree	Strongly Agree	Strongly Agree

Step 4. Identify Emergent and Future Conditions

Scenarios (one or more conditions)

Conditions	S1. Green Movement	S2. National Security Perspective	S3. Leader-by-Example	S4. Increased exposure of system	S5. Payback perspective
Increase in cyber threats	☐	☐	☐	☐	☐
National Renewable Portfolio Standards (RPS)	☑				
Electric vehicles become the focus of the "green" movement	☐				
Carbon tax/legislation	☑				
New environmental legislation	☑				
Advances in fuel cell technology	☐	☐	☐	☐	☐

Combining diverse conditions

Step 5. Elicit Experts on Scenarios

Scenarios (one or more conditions)

	S1. Green Movement	S2. National Security Perspective	S3. Leader-by-Example	S4. Increased exposure of system	S5. Payback perspective
Requirements - Baseline Rating					
R1. Backup power - E					
R2. Ridethrough backup - E					
R3.Reduce vulnerability to physica...					
R4. Reduce vulnerability to non-physica...					
R5. Blackstart cap...					
R6. Accommodate variety of science and other...					
R7. Constant frequency - E					
R8. Flexible islanding capability - C				MAJOR INCREASE	
R9. Improved energy efficiency - C	MAJOR INCREASE		MAJOR INCREASE		
R10. Outage detectability - R					
R11. Increase autonomous energy - R		MAJOR INCREASE		MAJOR INCREASE	

**Scenarios influence the relative importance of the performance criteria**

Step 6. Interpret Results

Prioritize alternatives and identify influential scenarios

Prioritize alternatives and identify threats across scenarios

	NVESD 300 Area Phase I A	NVESD 300 Area Phase IB	NVESD 300 Area Phase IC	NVESD 300 Area Phase IIA	NVESD 300 Area Phase IIB	NVESD 300 Area Phase IIC	NVESD 300 Area Phase IID	NVESD 300 Area Phase IIE
	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.
Baseline	7th	4th	6th	8th	3rd	5th	1st	1st
S1. Green Movement	7th	6th	4th	8th	5th	3rd	1st	1st
S2. National Security Perspective	7th	6th	4th	8th	5th	3rd	1st	1st
S3. Leader-by-Example	7th	4th	6th	8th	3rd	5th	1st	1st
S4. Increased exposure of system	7th	4th	6th	8th	3rd	5th	1st	1st
S5. Payback perspective	5th	1st	7th	8th	4th	6th	2nd	2nd

Influential scenarios
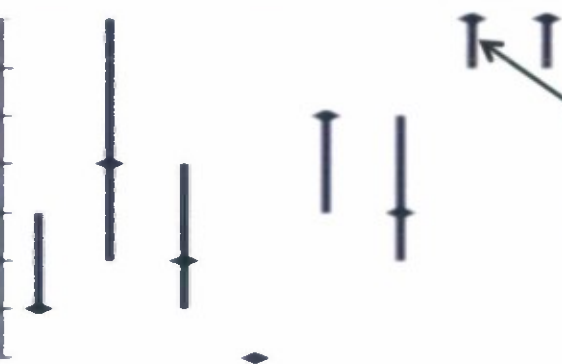
Robust technology

Step 6. Interpret Results (cont.)

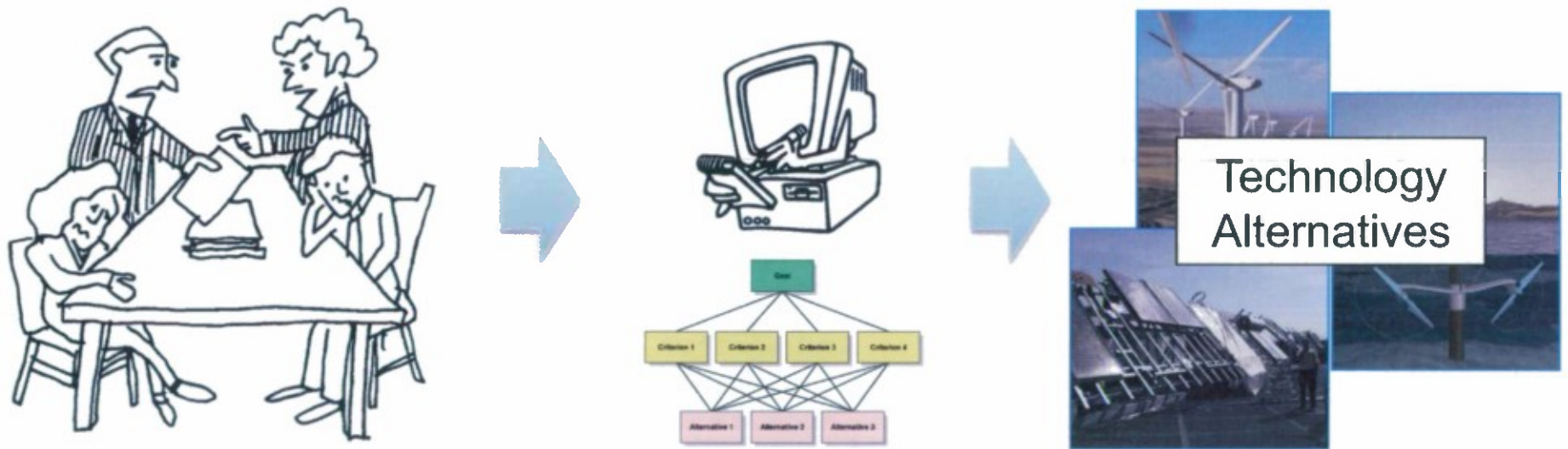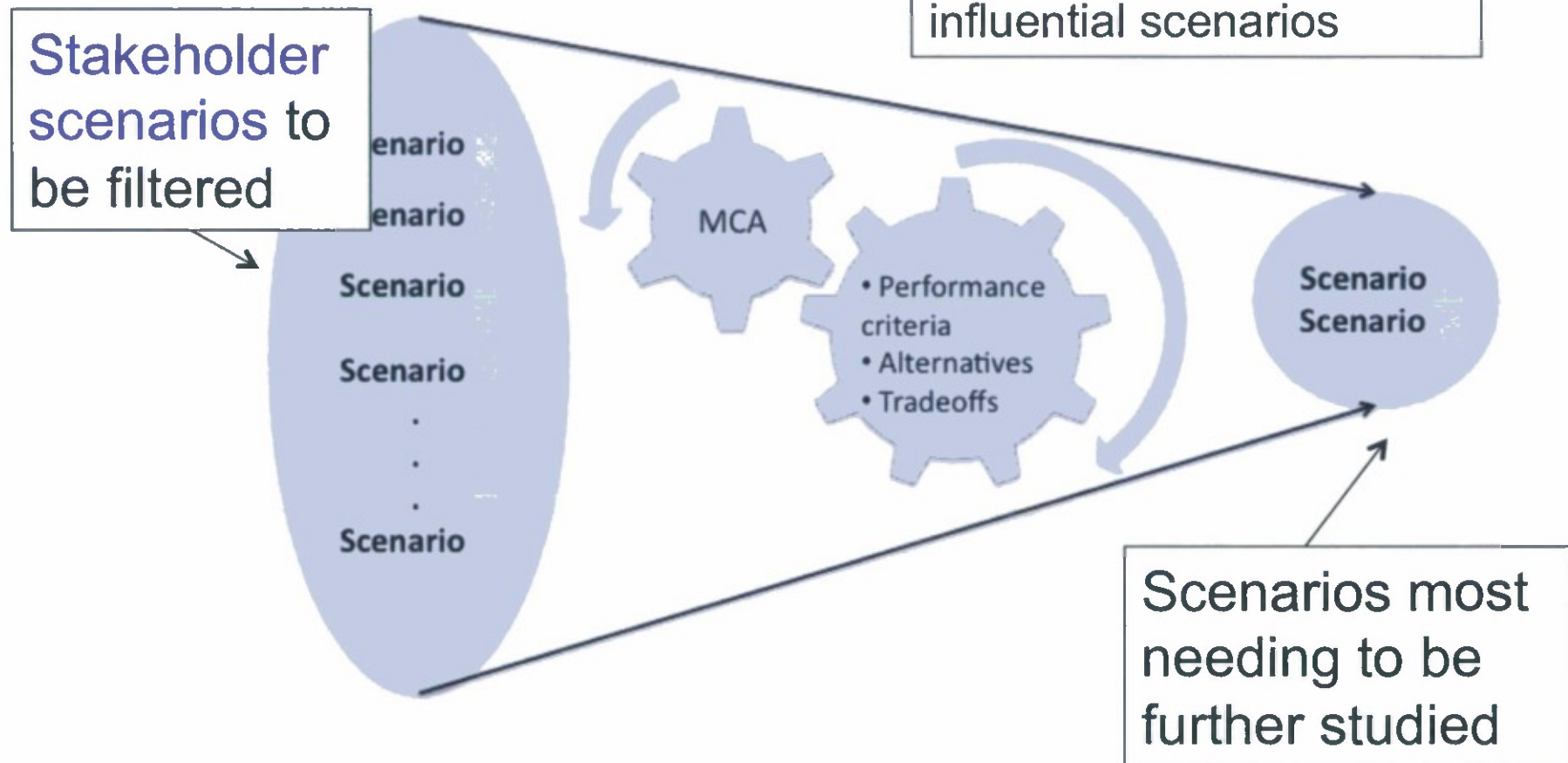| Enter summary notes on the results	
Best Performing Conceptual Designs	In all but the *Payback perspective* scenario, the conceptual design *FT. Belvoir NVESD 300 Area Phase IID* is the best performing. In the *Payback perspective* scenario, *FT. Belvoir NVESD 300 Area Phase IB* is the best performing.
Most Influential Scenarios	The scenario *Payback perspective* is the most influential and upsetting, causing *FT. Belvoir NVESD 300 Area Phase IB* to be prioritized over *FT. Belvoir NVESD 300 Area Phase IID*.

Results are reported to the energy working group to inform negotiation and strategic planning

Step 7. Iterate with all Previous Steps

A decision-aiding method incorporating **scenario analysis** and **multicriteria decision analysis** to address stakeholder **contention** during early phases of the systems lifecycle and to support **innovation** and discussion of requirements and alternatives.

Technology Alternatives

Significance of the Results

Identify opportunities and threats across the scenarios and identify influential scenarios

Stakeholder scenarios to be filtered

Scenarios most needing to be further studied

Summary of Accomplishments

Technology Alternatives

- Supported case study site to identify effective technology alternatives and influential emergent/future conditions

- Recommended gas turbines for the present, landfill gas, and liquid natural gas into the future

- Convened a stakeholder workshop to address cyber threat, security of gas reservoirs, regulations, etc.

- Tested the software tool with a dozen of the working group of military, industry, energy managers, tenants, vendors, others

- Published or submitted more than five archival papers, more than a dozen conference presentations or papers, and two book chapters

Contact

CR1000 Power Package

www.virginia.edu/crmes/energysecurity

lambert@virginia.edu

James H. Lambert, P.E., Ph.D., D.WRE

434-531-4529